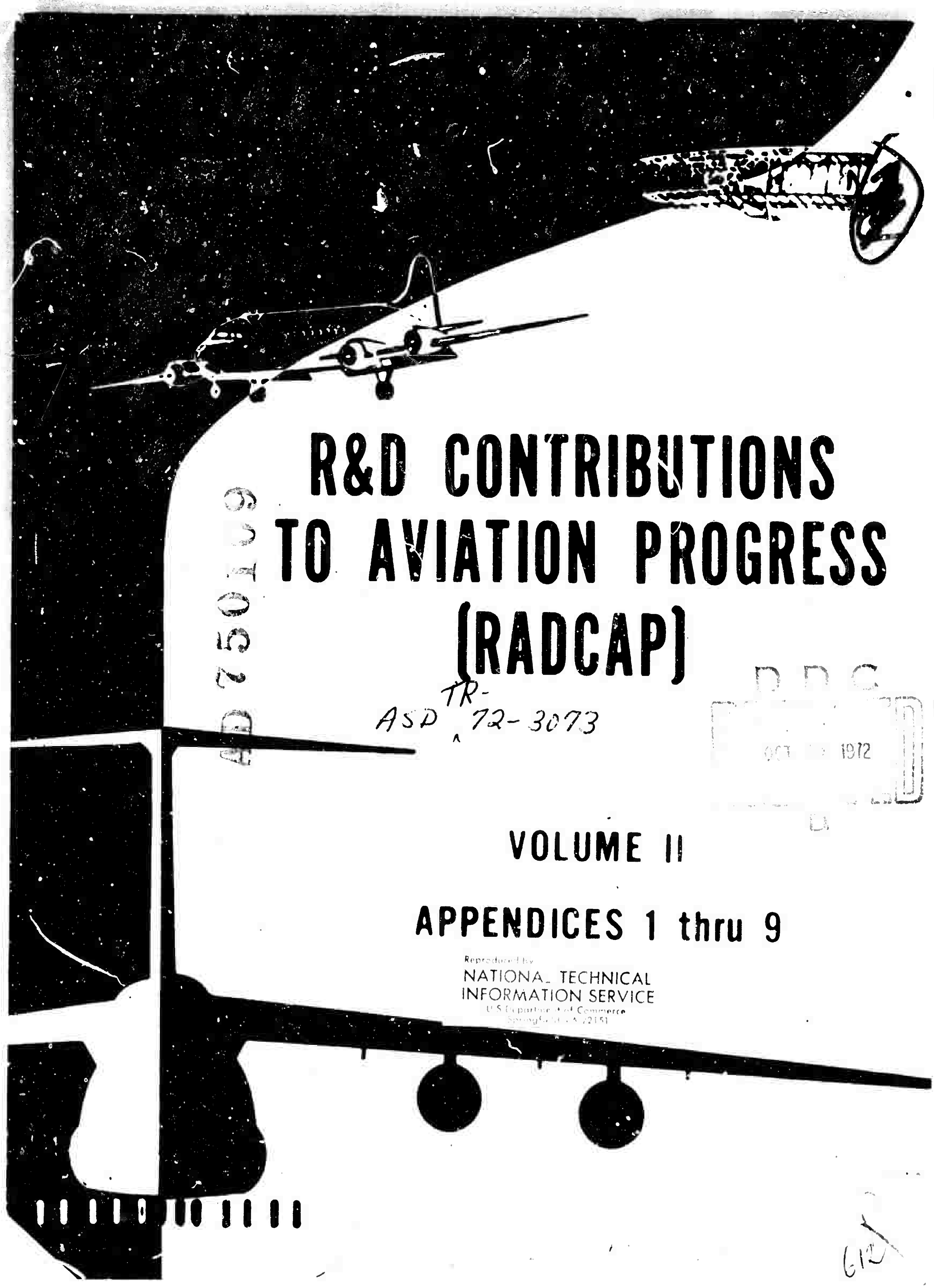

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R&D CONTRIBUTIONS TO AVIATION PROGRESS (RADCAP)

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APPENDICES 1 thru 9

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13. ABSTRACT

This report contains the detailed results of the joint DoD-NASA-DoT study of U.S. Aeronautical progress since 1925. This Volume II provides additional and supplementary information concerning the results discussed in Volume I, Summary Report of the same subject. Appendices 1 thru 6 cover the several technical disciplines in order to identify the major technological advances that have been made in aviation since 1925. Appendices 7 thru 9 cover the relevancy of currently planned and funded DoD aeronautical R&D programs to the R&D needs of civil transport aviation.

ASD 72-3073

RESEARCH AND DEVELOPMENT CONTRIBUTIONS TO AVIATION PROGRESS (RADCAP STUDY)

APPENDICES

1. PROPULSION AND POWER
2. METEOROLOGY
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4. MATERIALS
5. HUMAN FACTORS/AVIATION MEDICINE
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FOREWORD

The joint DoD-NASA-DoT Study of Research and Development Contributions to Aviation Progress (RADCAP) was accomplished to examine the significant technological advances that have been made in aviation since 1925, and to review and assess the relevancy of current and planned military aeronautical research and development programs to the R&D needs of civil aviation.

The study traces its origins to a report issued by the Senate Committee on Aeronautical and Space Sciences in January 1968. This committee recommended that "an in-depth study should be made to analyze the relationship between benefits that accrue to the Nation from aviation and the level of aeronautical R&D effort." In response to this recommendation, as well as to a report prepared by the House Subcommittee on Advanced Research and Technology in March 1970, a joint DoT-NASA "Civil Aviation Research and Development Policy Study," or "CARD" Study, was initiated, with the report being published in March 1971. This study placed emphasis on an examination of civil aviation benefits to the Nation, the relationship of research and development to these benefits, the criteria for Government support of civil aviation, and the identification of R&D needs appropriate to continued advance in the future.

Since the "CARD" Study looked at military contributions only in a general sense, Mr. William M. Magruder, Special Consultant to the President, suggested in a 9 September 1971 Memorandum to Mr. David Packard, Deputy Secretary of Defense, that a detailed study should be conducted to show the following: first, the flow of military technology that has made the U. S. Civil Air Transport Industry dominant in the Free World; and second, the changes in military requirements that might indicate that this flow of technology, or perhaps the timing of this flow, may no longer be of the same nature as in prior years. The DoD agreed that such a study could highlight the bonus effects of military programs and be valuable to civil aviation planning. The result was the preparation of a joint DoD-NASA-DoT Statement of Work for the effort and the initiation of the "RADCAP" Review.

The specific objectives of the study were established by a planning group comprised of DoT NASA, and DoD representatives, and were defined as follows:

1. To identify the major technological advances that have been made in aviation since 1925 - including background, sponsor, user, application, timing, and trends.

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2. To show the relevancy of currently planned and funded DoD aeronautical R&D programs to the R&D needs of civil transport aviation - research and technology, development, application and transfer process.

Overall guidance and direction for the study was provided by a Steering Group comprised of representatives from the DoD, NASA, and the DoT. The Study Team consisted of a Working Group comprised of representatives from DoD, DoT, and NASA, and nine Working Group Panels in various subject areas. The initial meeting of the Study Team was held on 13 December 1971.

Working within the framework of the specific objectives established and approved by the Steering Group, two corresponding tasks were formed, each requiring research and study from a different perspective. Working Group Panels accomplished the primary effort associated with each of the tasks, and the detailed results are incorporated in the Appendices of the RADCAP Report (Volume II). Appendices 1 through 6 cover the several technical disciplines and relate to the first objective of the study. Appendices 7 through 9 cover the relevancy and trend questions, and relate to the second objective of the study.

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APPENDIX 1

PROPULSION AND POWER

JOINT DoD-NASA-DoT

"R&D CONTRIBUTIONS TO AVIATION PROGRESS"

(RADCAP) STUDY

CHARLES R. HUDSON, JR.

USAF/AFSC (AFAPL/SF)

PANEL CHAIRMAN

AUGUST 1972

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Appendix 1

PROPULSION AND POWER

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SECTION I

INTRODUCTION

Propulsion has been, and continues to be the pacing subsystem in the development of new aircraft. Historically it can be shown that the ability to develop and produce successful high-performance aircraft has been made possible only through significant improvements in aircraft propulsion. The propulsion industry was given great impetus by World War II to provide ever increasing power for the existing, already designed, aircraft in the military arsenal. This additional power allowed the full combat potential of these aircraft to be attained. The period from 1945 to 1970 saw great strides in aircraft performance due chiefly to the advent and rapid development of jet propulsion. In contrast to the reciprocating engine era, the jet engine developed so rapidly as to demand new airframes at frequent intervals to match their new, much greater, performance levels.

In the reciprocating engine era, the methodology of engine development was quite simple. The engine developer was constantly upgrading the power production capability of his engines, but the incremental horsepower was only a few percent at a time and often connected with no increase in engine weight. The airframe designer was usually able to simply strengthen the engine mount or make minor center of gravity adjustments and thereby utilize this increased power production capability. With the advent of the turbine type engines, the technology advanced so rapidly that within a matter of only a few years the jet's thrust output was so drastically increased as to require a new airframe to adequately exploit its potential. An additional factor to be considered in the development of jet engines is their cost. The production cost of a World War II reciprocating engine was in the \$10,000 to \$25,000 range, but an engine of the J-57 class cost nearly ten times this amount. The development cost of late model jet engines is so great, some times being in the \$200,000,000 range, that a new methodology had to be developed for economical advancement of turbine engine technology. Additionally, the integration of a jet engine into a modern high performance aeronautical system has been found to be so complex that a new concept of dealing with this interaction had to be developed which treats the engine air flow from inlet completely through the engine to the exhaust nozzle, together with aircraft interactions on this air flow. These new methodologies are explained in detail in Section III of this Appendix.

This Appendix primarily covers military propulsion R&D. Also included are joint programs with NASA and the DoT, as well as the propulsion programs of NASA and the DoT that complement, or relate to, military efforts. A complete coverage of all Federal Non-Defense Agency programs in propulsion has not been attempted.

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SECTION II

SIGNIFICANT ADVANCES SINCE 1925

A. Reciprocating Engines

At the close of World War I, there existed huge quantities of war surplus engines (such as the OX-5, Hispano-Suiza, and Liberty) many of them in new condition. These engines were made available to the public at a fraction of their original cost and fulfilled the demand for engines until the mid-1920s. There was, therefore, little incentive for engine companies to invest in new engine designs. One enterprising individual did, however, venture the design of a new, as of that time unproven, radial air-cooled engine. The individual was Charles L. Lawrance and his firm, the Lawrance Aero-Engine Corporation, interested the US Navy in his engine and he successfully developed the 200 hp J-1 which was installed in the Curtiss TS-1 in 1922. This organization later became the Wright Aeronautical Corporation. At about this same time, several personnel formerly with Wright Aeronautical became affiliated with what later became the Pratt & Whitney Company. These engineers then set out to develop engines hopefully superior to the Wright Aeronautical products. Both Wright and Pratt & Whitney engines found ready acceptance in the aviation community, both military and civilian. It was one of this new breed of engines, the Wright J5, that powered Lindbergh's historic flight. Due to the aggressiveness of both of these companies, a long and successful series of engines were developed, almost exclusively under company sponsorship, until the late 1930s. Notable of the Pratt & Whitney series were the Wasp Jr., Wasp, Twin Wasp, Double-Wasp, and Wasp Major, with horsepower ranges from 450 to 3250. Wright Aero engines included the Whirlwind, Cyclone, Double Row Cyclone, Duplex Cyclone and Turbo-Cyclone models with ratings from 235 to 2500 horsepower.

The military services, by allowing the engine companies to include "engineering" as a production cost and then basing the final profit on this production cost, were, in effect, subsidizing this industry. Their engineering teams then proceeded with new engine designs for both military and civil use. It can thus be said that commercial air transportation, and the commercial engine business, flourished in the U.S. primarily as a result of Government subsidy. The development of radial air-cooled commercial engines was as much a result of Government policy as was the occasionally directly financed development of military engines.

In addition to the radial air-cooled engine development outlined above, considerable development of liquid-cooled engines was

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undertaken just prior to and during World War II. Since the commercial aviation market had little or no interest in this type of engine, its development was funded primarily by the military. Combat aircraft such as the P-38, P-39, P-40 and P-51 all utilized this type of engine, the Allison V-1710 chiefly powering the first three, and Allison V-1710's and Packard built Rolls-Royce's shared the P-51's.

B. Reciprocating Engine Fuels

In the early 1920's, Kettering and his associates discovered the anti-knock properties of tetraethyl lead (TEL). The Army Air Service experimented with TEL in 1922 but found it unsuitable for use in their equipment. The Navy began using TEL in 1926 to overcome heating and detonation in their air-cooled engines; first in the 400 HP Wasp and later in the 600 HP Hornet. The TEL was added to the aircraft tanks after refuelling. The Army Air Service followed suit in 1928, using the same procedure. In these years prior to 1928 it was ascertained that radical differences in engine performance resulted from the use of various fuels produced in assorted refineries in the U.S. and abroad. Rudimentary specifications were used for fuel procurement, and the underlying causes for these performance differences were investigated. In the years following 1928, however, a scientific investigation was undertaken to correlate engine performance vs the physical and chemical composition of fuels. A large degree of credit must be given to Mr. S. D. Heron, a Government employee, for the start of this investigation which, before it was fruitful, involved many disciplines such as engine builders, chemists, petroleum refiners, and chemical companies. The main problem to be solved concerned engine overheating and detonation (knocking) and led to the establishment of test methods and reference fuels defining the detonation characteristics of a fuel. In 1930 the first fuel specifications which included a knock (detonation) characteristic were approved. Numerous materials were investigated as to their detonation characteristics and it was found that certain octanes, especially iso-octane, exhibited superior resistance to knocking. The Army Air Corps undertook full-scale, and subsequently flight tests in 1934, of an iso-octane blend and proved its capability of greatly improving the HP output of engines. It was this work that led to the development of the 100 octane, and higher, fuels of World War II. To produce the anticipated quantities of iso-octane based fuels (the original estimates being greatly exceeded), a large production capability had to be established.

Between Pearl Harbor and VJ-Day, 19 billion gallons of 100/130 grade aviation gasoline were produced by the Allied nations (primarily the US). The cost of this fuel, f.o.b. refinery, was about

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3 billion dollars. Between June 1940 and VJ-Day, the facilities expansion program necessary to produce this fuel quantity cost nearly a billion dollars and was funded 75% by industry and 25% by Defense Plant Corporation (Government) funds. At the close of hostilities, this material was made available to commercial aviation operations and even, for many years, aided in the production of high octane motor fuels. The use of increasingly higher octane fuels allows the engine operator to produce more power from a given engine without overheating (or knocking) thus allowing him to take off with more payload. Another benefit is the ability to use leaner fuel/air mixtures thereby saving fuel and increasing range or decreasing operating cost.

C. The Supercharger

Even before WWI, the use of a supercharger to preclude the power loss resulting from altitude operation, was realized. No supercharged engines went into service during WWI. In the post-war years British and German experimentation, and flights, were conducted with experimental superchargers. The U.S. followed suit and by 1925 had several experimental supercharged radial engines which were used for test flights. The first U.S. production engine with gear-driven, built-in, single-speed, single-stage centrifugal supercharger was the P&W R-1340 which entered preliminary service in 1927. After 1930 virtually all military and commercial aircraft employed engines with single or two-speed centrifugal superchargers, with some military engines having two-stage units.

It is a well known fact that the reciprocating engine discharges approximately one-third of its energy through the exhaust system. Several persons, including Dr. Moss of G.E., suggested that this wasted energy be harnessed by a turbine which, in turn, could drive an air compressor, thus producing a more efficient cycle and, ultimately, produce more power from a given engine. For several years, Dr. Moss and Army personnel collaborated in the development of a turbosupercharger as a potential means of maintaining the HP rating of an engine at high altitude, and developed a unit which was subsequently tested on Pike's Peak in 1918. For the next twenty years, this development was continued with the main limitation being in the metallurgy of the turbine wheel. By the late 1930's, alloys with sufficient hot strength to allow the turbosupercharger to be fully operational had been developed, and upon the U.S. entry into World War II, made possible the superior high altitude performance of such aircraft as the B-17, B-24, P-38, and the P-47. In 1948 the Boeing 377 Stratocruiser entered operation with Pan American Airways to become the first commercial airliner tha employed turbosupercharging. The development of the turbosupercharger also had a great

influence on the turbojet engine, since the turbine problems of both were similar with respect to temperature vs strength.

D. Controllable-Pitch Propellers

The first application of a controllable-pitch propeller appears to be in a British aircraft during World War I. Several concerns in the U.S. were engaged in the development of variable-pitch propellers in the early 20's but, due to the mechanical complexity of the variable-pitch concept and general lack of air-worthiness of these units, at that date, it was not adopted. In the early 30's, the first practical two-position unit was developed by Hamilton-Standard for the military services.

The Boeing Company's 247, in 1933, was the first commercial aircraft to adopt a two-position variable-pitch propeller, since this was the only means of getting reasonable take-off payloads off of commercial airfields located at high altitudes such as at Denver or Cheyenne. In 1934 the 247's started conversion from these two-position propelle to constant-speed units incorporating automatically controlled pitch. Military operational use of two-position, and constant-speed propellers occurred the same year.

E. Reciprocating Engine Accessories

Concurrent with the development of reciprocating engines, many advances were made on the accessories for same. Notable amongst these were ceramic spark plugs, high altitude ignition systems, floatless carburetors, anti-foam agents for oil, and advanced oil system components. Essentially all of these items, largely investigated by the military services, were incorporated into the commercial reciprocating engines of the post World War II years.

F. Turbo-Jet Engines

Gas turbines had been built, and were capable of running under their own power, in the early 1900's. For several years, prior to World War II, proposals were made for the development of aircraft gas turbines in the United States. Several designs were formulated and some experimental work was conducted, but, since they were being considered as a direct replacement for the reciprocating engine, it was generally conceded that it was not competitive since nearly every design, even when extrapolated to high HP sizes, was estimated to weigh at least 50% more than a conventional reciprocating engine. During, and even preceding this time, and quite unbeknownst to the United States, work on a turbo-jet engine was progressing on the Whittle engine in Great Britain. Certain information filtered to

the U.S. concerning the Whittle engine, and when General Arnold visited England in the Spring of 1941, he was greatly astonished as to the progress that had been made, and that not only were engines being built but that they were about to be test flown. Shortly thereafter a Whittle engine was shipped to the U.S. and arrangements were made with the General Electric Company to build an experimental engine which was a direct copy of the British Power Jet's W-IX Engine. The first U.S. engine built by General Electric, and known as the I, ran excessively hot although it was not plagued by turbine bucket breakage as was generally the British experience. The main reason for a more satisfactory turbine in the U.S. engine was due mainly to the superior metallurgy, developed in the turbosupercharger work, which worked admirably in their engine. The engine was plagued, however, with surging and General Electric proceeded to redesign the compressor diffuser section, at which time the engine ran quite well. This redesigned engine, known as the I-A, was subsequently flown in a Bell P-59A in 1942, which was nearly a year before the British W-2B was flown.

The success of the U.S. endeavors in the turbojet field were many in the time period from World War II until 1956. The F-80 airplane was powered by the J-33 engine and set a new world speed record, saw combat in Korea, and the training version of same gave many military pilots their first jet training. The J-47 engine had a large production run, saw combat service in Korea, and was installed on the B-36 as booster engines for increased performance. It was the power plant for many military aircraft and this engine, too, greatly aided jet engine know-how. This time period saw the jet engine dominate the Navy fighter scene with the J-34 and the J-48 engines seeing combat service in Korea. The J-47 engine was also produced in large numbers (approximately 15,000) for the B-52, C-135, F-8's, A-3's, and several Century series fighters, and set a new level of performance, both thrust-wise and in engine life.

With respect to life, the early jet engines averaged only about 7.5 hours between overhaul. In the time period between 1948 and 1954, considerable emphasis was put on the matter of increasing this life and by 1955 many engines were capable of 1,000 hours. Prior to the 1,000 hour life, the jet engine had little interest to the commercial operator, but when it had arrived at this level, it became economically feasible for consideration. In the early 1950's, the maintainability of jet engines in the field was also given considerable attention. The early concepts of Jet Engine Field Maintenance (JEFM) developed by the military provided experience and basic maintenance instructions for early commercial airline operators.

The complexity of the jet engine was responsible for many advances in manufacturing technology. New techniques for large forgings used in turbines and compressors were developed. Advanced casting, explosive forming, protective flame spraying, and other important techniques had to be utilized to economically produce jet engine parts. Many advances in high temperature metallurgy were brought forth, as well as the impetus for entirely new metals such as titanium. Many studies in the field of combustion had to be solved to produce the high heat release combustors required in the jet engine. Pioneering work by NACA (1946-1958) in cooled turbines made high turbine inlet temperatures, so important from a thermodynamic standpoint, more attainable. Since the engine had to operate from sea level to extremely high altitudes, burner designs had to be accomplished without the problems of combustion instability or flame blow-out. This need for a wide altitude operational range also necessitated changes in fuels with respect to their burning qualities, volatility, and thermal stability. The early jet engine fuel controls consisted simply of a fly ball governor for speed control and a barometric valve for altitude compensation. As the engines became more complex, additional parameters had to be measured to properly adjust the fuel flow, such as compressor inlet temperature, compressor discharge pressure, turbine discharge and, in the case of the variable geometry twin-spool engines, as many as thirteen parameters had to be monitored to adequately control the engine to the pilot's demands. In brief, the jet engine required the pursuing of many technologies to make it a success. These technologies, to name a few, included high speed anti-friction bearings, high efficiency compressors and turbines such as designed by NACA in the 1950's, high heat release burners, and all the attendant metallurgical advances necessary to make the engine a success and long lived. Due to the increasing interest by commercial airline operators, a symposium on jet "know-how" was held at Wright Field in June 1956. This symposium provided a sounding board for revealing military jet powered aircraft experiences to the commercial operators. Since a large technology base had been developed by the Government, the jet engine, when desired for commercial application, was essentially ready. The first commercial use of jet engines in a scheduled airline was that of the J-57 (commercial designation JT-3). It is interesting to note that the expenditures on jet engines and test facilities for same from the I-A to the advent of this commercial jet flight were approximately 4.0 billion dollars supported heavily by the military or military profits. A representative listing of commercial engines which were first developed as military designs is given as Table 1.

TABLE 1

COMMERCIAL ENGINE DERIVATIVES OF MILITARY ENGINE DEVELOPMENTS
(REPRESENTATIVE LISTING)

MILITARY ENGINE			COMMERCIAL COUNTERPART			
DESIG-NATION	FIRST FLIGHT	AIRCRAFT	DESIG-NATION	FIRST FLIGHT	AIRCRAFT	NUMBER BOUGHT*
J-47	MAY 48	F-86, B-47	NONE	----	CERTIFIED ONLY	----
J-52	APR 60	GAM-77, A-4, A-6	JT-8A	FEB 63	JT-8D (FAN) 737, 727, DC-9	4501
J-57	APR 52	B-52, C-135, F-8, A-3, 100 SERIES FIGHTERS	JT-3C	MAR 53	707, DC-8	612
J-60**	JAN 60	C-140, T-39 T-2B	JT-12	FEB 60	JET STAR, SABRELINER	1180
J-75	MAY 56	F-105, F-106	JT-4A	NOV 58	707-320	660
J-79	JUL 57	F-104, F-4, B-58, A-5	CJ805-3	JAN 59	CONVAIR 880	366
J-85	JAN 59	GAM-72, T-38, F-5, T-2C	CJ-610	LATE 61	JET COMMANDER, LEAR JET	1139
TF-33	MAR 61	B-52H, C-141	JT-3D	JUN 60	707, DC-8	4060
TF-35	NONE	----	CJ805-23	JAN 61	CONVAIR 990	272
TF-37	NONE	----	CF-700	AUG 64	JET FALCON	697
TF-39	JUN 68	C-5	CF-6-6	AUG 70	DC-10	136
T-53	CIR.56	UH-1	T53L13	----	BELL 205	783
T-55	SEP 61	CH-47A	T-55L	----	VERTOL 114	63
T-56	DEC 56	C-130, P-3	501D-13	DEC 57	ELECTRA	2213
T-58	MAY 58	H-1, H-2 H-3, H-46 SERIES	CT-58	JUL 59	S-62, S-61 VERTOL 107	352
T-63	----	OH-6A, OH-58 OH-5A	250-C18	----	BELL JET RANGER HUGHES 500, HILLER FH-1100	2600
T-64	----	CH-53 SERIES	CT-64	----	SIKORSKY S-65	----
T-73**	----	CH-54 SERIES	JFTD-12	----	SIKORSKY S-64	78

* AS OF 15 FEB 1972 - INFORMATION PROVIDED BY ENGINE MANUFACTURERS.
** THIS WAS A COMMERCIALLY DEVELOPED ENGINE WITH MILITARY APPLICATIONS.

G. Turbo-Fan Engines

The first U.S. turbo-fan engine was the XJ-49 built by Packard Motor Company under contract to the Army Air Corps during the period mid-1943 to 1946. Work on this engine, an aft-fan, was terminated for lack of a suitable application. Starting early in 1947, a continuous assessment of the desirability and applicability of a turbo-fan engine was made. In December 1948, Mr. Opie Chenoweth, Technical Director of the Power Plant Laboratory, recommended vigorous pursuit of the turbo-fan concept. In October 1949; Hq USAF recommended a turbo-fan be applied to the B-52 aircraft. It was during this time period (July 1947) that Government funding of the Pratt & Whitney J-57 was started. The J-57 series engines were funded in the amount of $386,000,000 between July 1947 and September 1955. From late 1949 to September 1955, approximately $220,000,000 was spent developing the Pratt & Whitney J-75 engine, which was similar in design concept to the J-57, only larger. During this same general time period, several other jet engines were Government-funded at Pratt & Whitney with total expenditures with that company being upwards of $800,000,000. In September 1955, Pratt & Whitney proposed to WADC (the predecessor of the present Aeronautical Systems Division) the manufacture of a turbo-fan engine. The design incorporated a J-57 gas generator and a fan consisting of the first three stages of a J-75. Having not received immediate financial support from the USAF, Pratt & Whitney decided to build that turbo-fan without Government financial support but with USAF approval to use Government hardware. This was accomplished in a period of approximately ten months from proposal to first running.

It should be noted, from a historical standpoint, that in the period from 1956 to 1958 there were increasing interests in the turbo-fan engine, both from engine manufacturers and from the aircraft operations people. It must be recalled, however, that during this period there was a waning interest in the military in the area of air-breathing engines. The undertaking of a completely new engine development program for a turbofan engine, which might have cost upwards of $200,000,000, would have received little consideration at that time. Pratt & Whitney had the components of existing J-57 and J-75 engines readily available to them and the first "build" of their turbofan was successful. It is conceivable that turbofan development might never have occurred, or at least have been delayed for years, if Pratt & Whitney's attempt had failed.

A turbofan development was also undertaken with General Electric starting in mid-1954 known as the G.E. XTF-31 (D-2). This program was to produce a front fan version of the military J-79 and was funded in the amount of $15.6 million dollars. The development was

relatively unsatisfactory and was terminated in early 1956. A variation of this development, an aft-fan version of the J-79, known as the X-220, and funded with $5,000,000 of R&D money was conducted until August 1958, at which time it, too, was terminated due to lack of suitable characteristics for military application. The engine, however, was continued forward on company funds and was qualified for flight in December 1959 and was known as the CJ-805-23 and found service in the Convair 990 aircraft. The commercial derivative of the J-79 Turbojet is used in the Convair 880 aircraft and is known as a CJ-805-3 engine. Many other Government derived turbo-fans were transitioned to commercial equivalency and these are also listed in Table 1.

In 1964 the USAF sponsored two engine developments, one with General Electric and one with Pratt & Whitney, for the C-5 aircraft. The final development award for the C-5 aircraft engine was to General Electric, and resulted in the development of the TF-39 engine. A commercial variation, relatively minor in magnitude, of this TF-39 resulted in the General Electric commercial CF6 engine, currently being used in the DC-10 aircraft. Recognizing the derivation of this engine from its military prototype, General Electric has agreed to repay approximately 20 million dollars to the U.S. Government by means of an assessment on each engine sold for commercial purposes. The engine development by Pratt & Whitney was designated as the JTF-14 and was Government funded for 25 to 30 million dollars. Upon selection of the G.E. engine for the C-5 application, Pratt & Whitney elected to develop a modification of the JTF-14 on company funds. This engine, designated the JT-9D, is used in the 747 aircraft.

H. Turbo-Shaft Engines

Several early turbo-shaft engine developments were undertaken by the U.S. Government and they too found application in commercial aircraft. The T-56 (501-D13) was used in the Electra's, the T-64 (CT-64-820), the T-58 (CT-58), and the T-63 (250-C18) were applied to many commercial helicopters. The T-64 was also used for the DHC-5 Buffalo STOL.

A series of small gas turbine engine developments sponsored principally by the Army was initiated in the 1950's. Typical of these were the Lycoming T-53 and T-55 and the Allison T-63. These gas turbine developments led to the ultimate replacement of the reciprocating engine as the prime power plant for rotary wing aircraft and resulted in the present widespread acceptance of the gas turbine in both military and commercial helicopters.

Other uses of turbojet and turboshaft engines in the form of ground power generating units should also be mentioned. Units employing turbine type engines, ganged to a common output, are in use as standby or "Topping" generating stations. Units of this type can sense a power failure, be started quickly, and provide standby power for emergency purposes. Several turbine engine variations have been used as prime movers in the area of pipeline pumping, and shipboard gas turbine engines have been developed using the military turbojet or turboshaft predecessors as their basis. One very recent marine and industrial gas turbine, the General Electric LM2500, rated at 25,000 HP, was derived from the TF-39 core engine. By adapting it to burn heavy fuels, treating it against corrosion by salt water, and several other relatively minor adaptations, it was ready for proof testing. It is anticipated that the LM2500 will meet the propulsion needs of commercial and military ships through the 1990's.

I. Thrust Reversers

The concept of having a device to reverse the thrust generated by a jet engine was set forth in patent form in the early 1940's. This sort of device, hereinafter known as a Thrust Reverser, was applied to reciprocating engines quite frequently in both military and commercial applications. The U.S. studied the potential uses of thrust reversers and seriously considered the use of same in the mid-1940's, and the U.S. Navy actually flight tested one during this same time period. The principal drawback to a thrust reverser for a jet engine is its weight, and considering this penalty, together with the generally good landing fields available to military aircraft, its use was deferred in favor of flight performance. Starting in 1953, the USAF became more serious in its considerations of thrust reversers and undertook several reverser developments, conducted flight tests of same, and produced a "Thrust Reverser" handbook. The commercial application of thrust reversers became common with the advent of the early commercial jet powered aircraft, in order to provide better operating economies. The first military application of a thrust reverser was on the C-141 aircraft which was designed to be of primary use as a troop and supply aircraft for forward operations.

J. Fuels and Lubricants

The development of high octane fuels for reciprocating engines has already been discussed in paragraph I.B. above. With the advent of the turbojet engine, it was readily apparent that this type engine was much less demanding of a fuel. The turbojet engine had no octane requirement, could burn a wide range of petroleum products,

and, therefore, could burn relatively cheap petroleum distillates. The first jet fuel for military operations was lighting grade kerosens such as burned in lamps. Due to the performance capability of jet engine powered aircraft, deficiencies in this product, such as inadequate freezing protection, erratic burning, and carbon formation were observed. In 1944, a military specification for an aircraft grade kerosene was prepared and this material was designated JP-1. Since the quantities of JP-1 (kerosene) were deemed inadequate for envisioned military operations, other fuels were developed and numerically designated such as JP-3 and JP-4. Upon the adoption of jet powered aircraft for commercial uses, these types of fuel were adopted by the airlines nearly verbatim and are designated as ASTM Jet-A and Jet-B. The use of Jet-A versus Jet-B is often predicated on cost and the difference in cost is generally one of whether it is, or is not, taxable.

A somewhat similar situation existed in the oil development picture for jet engines. It was recognized at an early date that petroleum oils would not be suitable for high performance jet engines, such as the J-57, and a new series of military oil specifications was developed. Two military specifications, MIL-L-7808 and MIL-L-23699 were developed for military aircraft and these products are the ones generally used in commercial jet aviation.

K. On-Board Power Generation

Early military aircraft operations which required electrical power aloft simply used an automobile storage battery which was charged on the ground, utilized in flight, and then recharged upon landing. As engine development progressed, generation equipment mounted on the engine, was incorporated to furnish more and longer duration needs. Later developments resulted in multi-engine installations incorporating voltage regulation, filtering, and capability for parallel operation. These systems were used in most of the World War II aircraft and some post World War II commercial reciprocating aircraft. During this same time period, some military aircraft utilized the alternator/rectifier type of D.C. power system which had a weight advantage and, having no commutator, required less maintenance. These systems, too, were applied to commercial aircraft. Power requirements for the B-36 were so large as to require a considerable technology increase in power generation. To accomplish this, a 3 phase, 400 cycles, 120/208 volt system, in conjunction with a Constant Speed Drive was developed. This system, due to the high voltage, allowed a weight reduction in copper for wiring. The constant frequency alternating voltage produced by the Constant Speed Drive, together with the 3 phases, allowed the utilization of reversible induction motors; again, saving weight, eliminating

brushes, and reducing maintenance problems. The system now in commercial use by most of the jet powered aircraft can be considered a direct descendent of the system developed for the B-36.

L. Aircraft Lighting

Lighting for the interior of military aircraft progressed from hand-held flashlights, to shielded incandescent lamps, to indirect incandescent lighting, to ultraviolet excited fluorescent displays. Exterior lighting to allow formation flying at night was first used on military aircraft and landing lights, adapted from automobile head lamps, were first utilized by military aircraft. Present day aircraft interior and exterior lighting was derived from these basic military developments.

M. Runway Lighting

Electrical runway lighting was first applied to military airfields. The early lighting systems were of the parallel wire variety, utilizing household lighting concepts. Early work done by the military developed a series lighting arrangement utilizing only one wire, directly buried isolation transformer, and high intensity lamps. This is the type of lighting system now generally used by commercial airports. An additional form of runway lighting utilizes "Strobe" lights and was instituted as a commercial undertaking as an attention getter. Since commercial airports were frequently near to inhabited areas, the strobe light voided the frequent problem of airliners trying to land on brightly-lit residential streets.

SECTION III

CURRENT AND PLANNED R&D EFFORTS

A. Advanced Technology Engine Development Programs

In 1959, it became evident that the existing propulsion technologies would not provide sufficient advancement in weapon system design to satisfy new system requirements. Component technology indicated the need for a bold new design approach. In addition to using the Component Improvement Program (CIP) to increase existing engine life and solve service derived deficiencies, a new experimental advanced development engine demonstrator program was initiated. This program was called the Lightweight Gas Generator (LWGG) and had as its objectives to demonstrate the highest possible gain in overall engine performance. Methods of increasing the compressor work per stage, combustor heat release, and turbine inlet temperatures were investigated. The demonstrator engine established the feasibility that propulsion systems could be built with 30-40% reductions in specific fuel consumption and with thrust-to-weight ratios up to 10 to 1. This program evolved into the Advanced Turbine Gas Generator Programm (ATEGG) in FY 1965.

In 1960, it also became evident to the Army that existing small engine technology would not provide sufficient advancement in weapon system capability. A new design approach was incorporated to support the Army's need for effective forward air mobility. The Army initiated small engine component technology investigations and subsequently the "1500 Shaft Horsepower" demonstrator program, which was the combination of many of the component technology advancements. This engine program has demonstrated a 30% improvement in power-to-weight ratio with a corresponding 25% reduction in specific fuel consumption.

The results of the ATEGG and APSI (Aircraft Propulsion Subsystems Integration--ATEGG's companion program which addresses system responsive components and airframe/engine compatibility and integration techniques) programs are just now reaching inventory application as completely developed propulsion systems. The General Electric TF39 installed in the C-5A aircraft and the Pratt & Whitney JT9D installed in the Boeing 747 are the first military and commercial systems to use this new technology. This same technology is being applied in the propulsion systems for the F-14B, F-15, B-1 and the McDonnell Douglas DC-10 aircraft. The 1500 Shaft Horsepower demonstration program, having started later, is about four to five years from inventory introduction. The technological advancements

and the high reliability required for future gas turbine propulsion systems will be obtained under advanced development in the Air Force ATEGG and APSI programs, the Army STAGG (Small Turbine Advanced Gas Generator) program and the Navy PCT (Propulsion Component Technology) and Advanced Propulsion for V/STOL Aircraft programs.

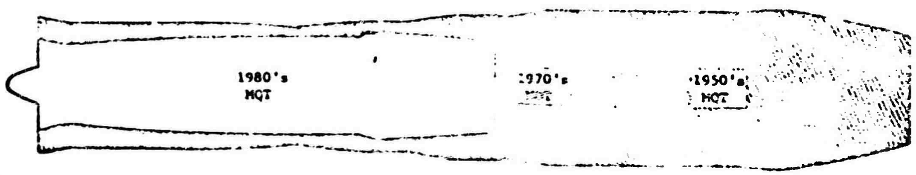
The significant past progress and the availability of improved components which have been tested and evaluated in demonstrator engines will allow projected propulsion system advancements to be planned with a high degree of confidence. Figure 1 illustrates the benefits in engine size and key performance parameters that can be achieved through advanced technology. However, the development and application of a new propulsion concept can require up to 20 years from inception to Service introduction largely because the needs for new concepts, although advocated, have not been funded and pursued early enough in the weapon system conceptual stage.

For free world, non-U.S. countries, Great Britain is expected to maintain its current technological leadership in the development and production of aircraft propulsion systems. The Pegasus 11 turbofan, used to power the Harrier V/STOL aircraft, is the world's first production lift/cruise engine, and Britain's direct lift engine technology currently paces free world state-of-the-art. The British are also pioneers in the development of three-spool and contr-rotating compressor designs. British subsonic turbofans such as the RB.168(TF41) and RB.211, and the supersonic RB.593 for the Concorde are having substantial impact in the military and commercial transport aircraft markets in both Europe and the United States.

The turbine engine has been used to power aircraft for just over two decades. Although great progress has been made in turbine propulsion, it is yet in a comparatively early phase of its growth. To appreciate this fact, it is important to look briefly at the technology trends for several of the most important performance indices. Figures 2 and 3 show the progress which has been made and which can be realized in the future if adequate research and development is applied to the technological problems.

In the past, system demonstrator engines were not initiated until a "firm" system requirement was established. The propulsion system was then optimized for this specific system requirement and the program was oriented to provide concurrent performance and structural integrity test verification. In this situation, the development schedule was necessarily very short with minimum advancement of technology. This type of advanced development approach proved to be very costly and too often resulted in severe structural/performance interrelated problems. Conversely, programs which have been

Engine Size Improvement - Comparative Thrust Engines



Performance Improvements Over Typical 1950's Engine

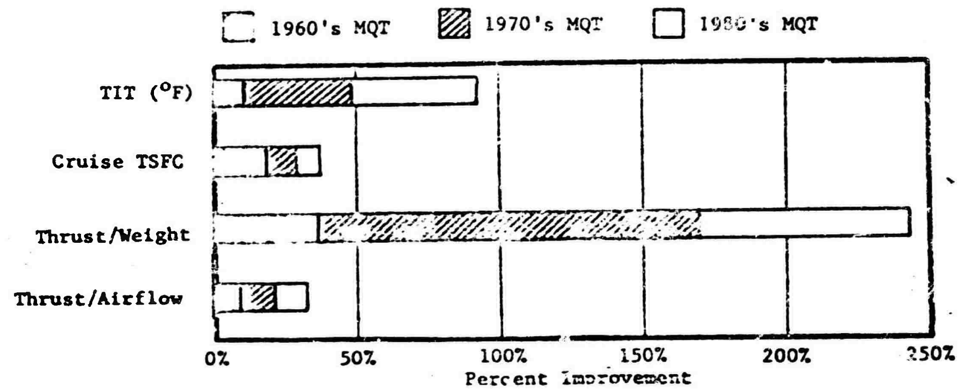


Figure 1 - Engine Technology Improvement

TECHNOLOGY TRENDS OF TURBOJET/TURBOFAN ENGINES

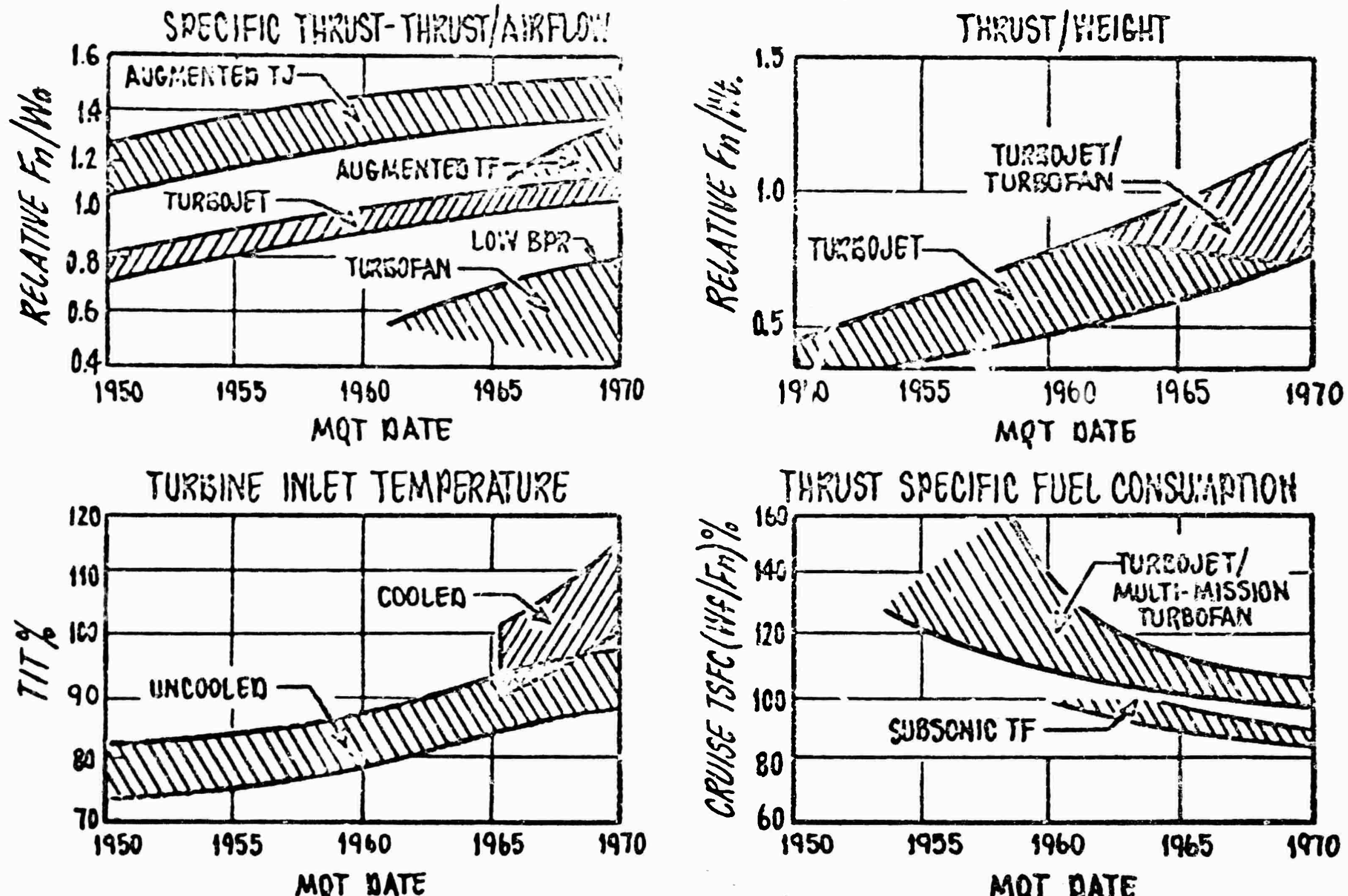


FIGURE 2

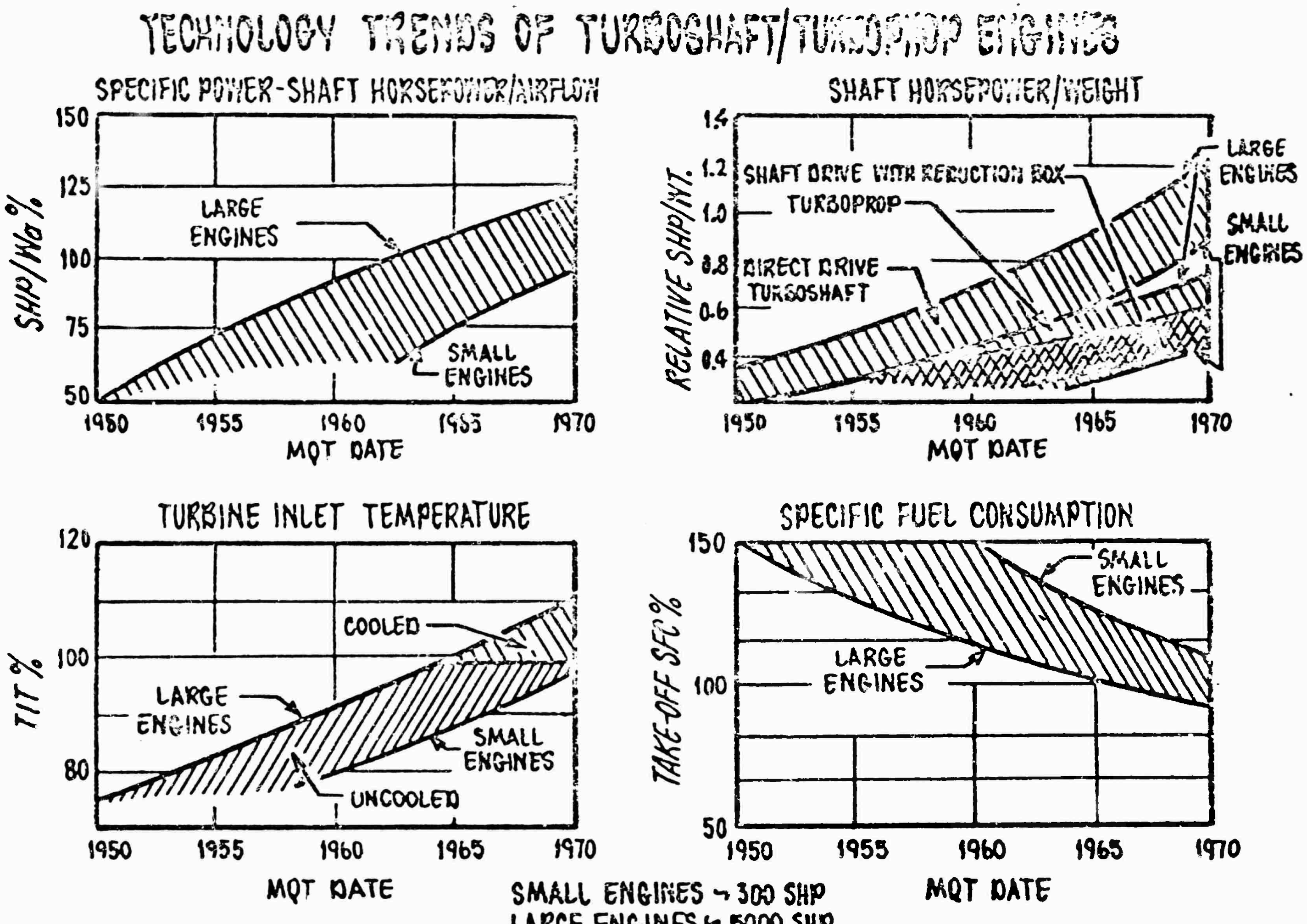

TECHNOLOGY TRENDS OF TURBOSHAFT/TURBOPROP ENGINES
SPECIFIC POWER-SHAFT HORSEPOWER/AIRFLOW
SHP/Wa %
150
125
100
75
50
1950
1955
1960
1965
1970
MQT DATE
LARGE ENGINES
SMALL ENGINES
SHAFT HORSEPOWER/WEIGHT
RELATIVE SHP/WT.
1.4
1.2
1.0
0.8
0.6
0.4
SHAFT DRIVE WITH REDUCTION BOX
TURBOPROP
DIRECT DRIVE TURBOSHAFT
LARGE ENGINES
SMALL ENGINES
TURBINE INLET TEMPERATURE
TIT %
120
100
80
COOLED
UNCOOLED
SPECIFIC FUEL CONSUMPTION
TAKE-OFF SFC %
SMALL ENGINES ~ 300 SHP
LARGE ENGINES ~ 5000 SHP

FIGURE 3

conducted with initial emphasis on performance or flow path definition, followed by adequate structural integrity testing, showed a higher rate of achievement at lower cost.

To profit from past experience and to provide for the timely availability of the advanced propulsion needed to satisfy future weapon system demands, a new approach has been defined for achieving the level of confidence required for initiation of engine development. It assures the aggressive exploitation and transition of advanced propulsion technology through improvement of existing engines or in new engine development programs at a reduced level of risk and with minimum cost. This approach, illustrated in Figure 4, is implemented under the Exploratory and Advanced Development programs and is based upon developing advanced gas generator components (scalable compressors, combustors, and turbines) and system responsive components (inlets, fans, controls, power turbines, exhaust nozzles, and augmenters) which have a maximum degree of flexibility. These programs will also draw upon the technology being developed by NASA in their component and engine programs. These are combined in an advanced technology demonstrator engine to establish the propulsion performance and structural characteristics required for a class of military systems and to provide for the inlet-exhaust system design criteria and integration techniques necessary to assure installed propulsion system performance. This demonstrator engine will be flexible and scalable in both size and performance to satisfy the range of characteristics required by the various systems within the class. Initial test emphasis will be placed on performance definition with follow-on emphasis on structural integrity of flightweight components. Early initiation is justified on the basis of wide application potential and will provide maximum exploitation of promising advanced technology. As requirements become firm and attention focuses on a particular system to meet an urgent military need, one can proceed directly into engine development or, where the risk is high, a system demonstrator engine may be dictated prior to engine development. The additional testing would be predicted upon total specific system needs. The system demonstrator, tailored to the specific application, would provide the full and credible performance and structural integrity verification required as the basis for the decision to proceed into full scale engine development.

Engineering Development and Operational System Development are the recipients and the logical progression of the Advanced Development technology as schematically illustrated in Figure 5. If a short reaction time is dictated by the system development schedule, advanced gas generator and system responsive components technology could proceed directly into the engine development phase with inherently higher risks.

Figure 4 Engine Development Approach

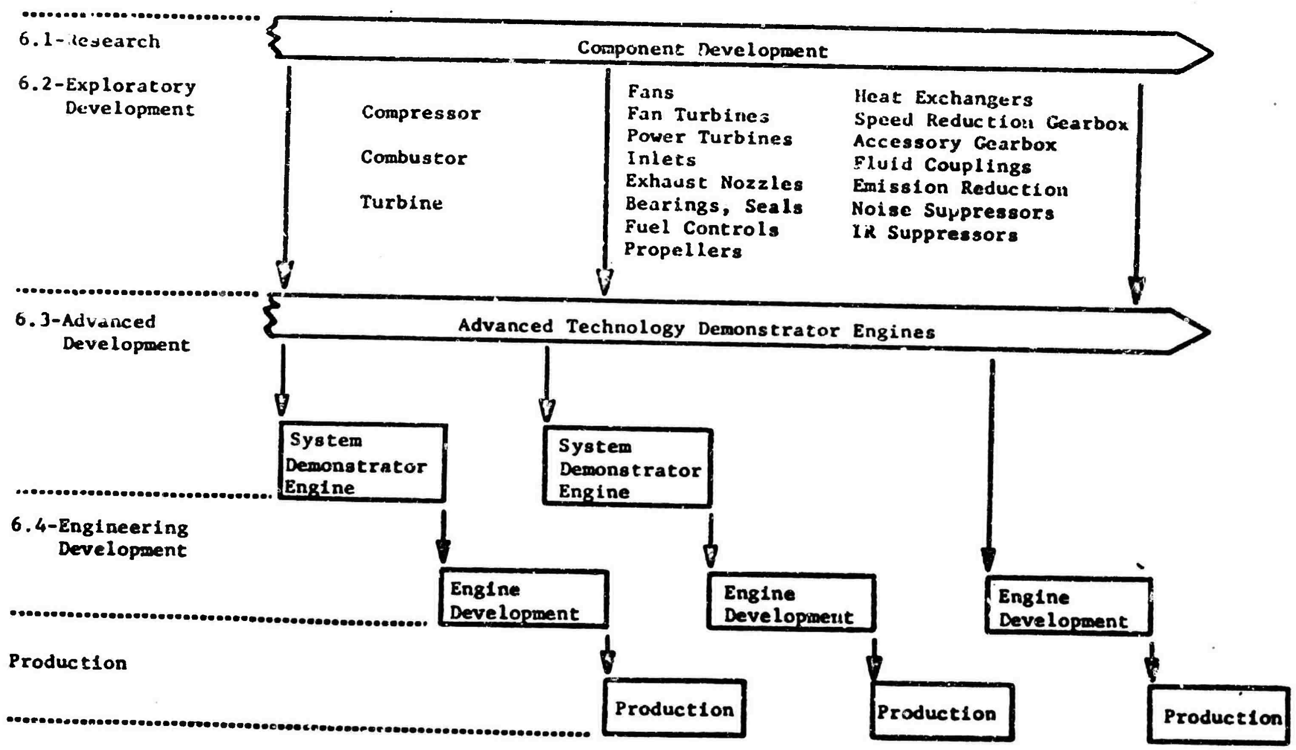
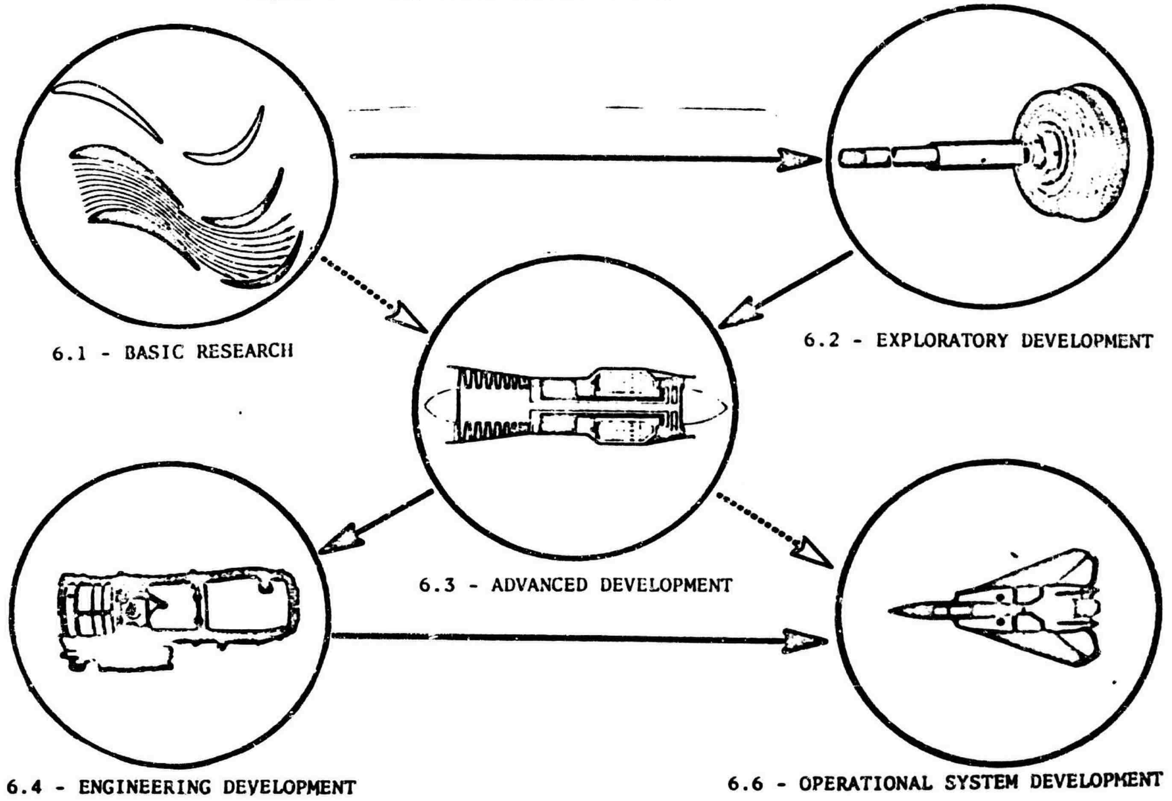


Figure 5 - Propulsion System Development Schematic



There are, at the present time, fifteen Advanced Development engine programs. The salient features of each of these programs are outlined below.

The first four programs (1 - 4) are being conducted under the Air Force ATEGG Program.

1. The Detroit Diesel Allison Division is presently running the GMA-100 gas generator consisting of a high pressure, high efficiency, variable-geometry compressor, short combustor, and a two-stage turbine. The core is oriented for high efficient transport type of an engine.

2. The General Electric GE14/J1B1 is presently under test. The compressor is highly loaded with medium pressure ratio. It has a carbureting combustor and a single-stage very high temperature film/impingement air-cooled turbine. The gas generator is being developed for the transonic/supersonic category of engines.

3. The Pratt & Whitney Aircraft PRW 535 is undergoing cyclic test. This gas generator has an advanced transonic compressor with cantilevered stators and drum rotor construction, a premix combustor, and a high temperature single stage transpiration cooled turbine. This gas generator technology is being developed for the transonic/supersonic type of propulsion systems.

4. Teledyne CAE (Continental) is running the Model 440-2 gas generator. It features an axial compressor followed by centrifugal compressor, vaporizing combustor, and a two stage turbine. The gas generator technology is being developed for use in engines in light to medium gross weight logistics aircraft and lightweight fighters.

5. The General Electric Co. is developing a "Quiet" engine under contract to NASA. The engine, using a CF-6 core with a fan designed for low noise, operates at a bypass ratio of 5 and produces 22,000 lbs sea level thrust. The noise objective of this engine is 15 to 20 PNdB less than a JT3D. Full nacelle treatment for noise suppression could result in a final noise level of 90 EPNdB for a four engine aircraft at the FAA FAR36 specified measuring points.

The next four programs (6 - 9) comprise the Army Small Turbine Advanced Gas Generator (STAGG) Program. STAGG is aimed at advanced core technology which will support future DoD small engine applications with primary orientation towards aircraft powerplants and auxiliary power units (APU), but also towards various other applications including marine and vehicular engines and electrical power

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generation. The STAGG program was initiated in Nov 71 to demonstrate performance improvements up to 25% reduction in SFC and 40% increase in specific horsepower in the 1-5 pps airflow range.

6. The Pratt & Whitney STAGG is in the 3-5 pps airflow range and features a centrifugal compressor with a close coupled inducer, an annular radial inflow combustor with air assist atomizing fuel nozzles, and a single stage cooled axial turbine.

7. The Lycoming STAGG, in the 3-5 pps airflow range is a two-stage axial and single stage centrifugal compressor, a reverse flow annular combustor with atomizing fuel nozzles, and a two-stage cooled axial turbine.

8. The AiResearch STAGG is in the 1-2 pps airflow range and features a single stage centrifugal compressor, a reverse flow annular combustor with vaporizing fuel injectors, and a radial inflow turbine featuring nozzle cooling.

9. The Williams Research STAGG, in the 1-2 pps airflow range, includes a single stage centrifugal compressor, an annular combustor with rotating slinger fuel injection system, and a single stage axial turbine featuring nozzle cooling.

10. The Navy's Propulsion Component Technology (PCT) Program, as planned, provides for the development of turbine engine components which will have wide propulsion applicability, and is directed to support related developments in the V/STOL area. This program is part of the Navy Aircraft Propulsion (Advanced) Program which includes two other projects: the first of which is Advanced Propulsion for V/STOL Aircraft, wherein preliminary aircraft and design will be studied to identify the V/STOL propulsion systems best suited for weapon system applications; the second project covers an in-flight fully modulated thrust reverser control system.

11. NASA, in conjunction with the Navy, has a small engine program. The goals of the program are to develop an engine, in the less than 10# air/sec class, embodying low cost and, at the same time, providing a suitable performance for a Navy missile application. Design and fabrication of selected components are being done under contract, then the remainder of the components, their integration and test, will be conducted "in-house" by NASA.

12. NASA-Lewis also has the Lift Fan Technology Project with objectives of developing necessary engine and component technology required to select the most suitable propulsion system for the aircraft, followed by a detailed investigation of the selected system.

Contract and in-house studies will aid in selection of the most suitable configuration and identify problem areas. Investigation of certain components (i.e., fans, tip turbine, integral drive fan turbine, seals) are being made to explore problems now identified. Component and integrated package programs will emphasize low noise as a prime objective. Lewis responsibility also includes propulsion support to the NASA-Ames Lift Fan transport program.

13. The NASA program on a quiet STOL experimental engine is outlined in Section III-C on Engine Pollution Control.

The last two programs (14 - 15) outlined below are being conducted under the Army's 1500 Shaft Horsepower Demonstrator turboshaft engine program, which was initiated in 1967. This multi-objective program was aimed at reducing fuel consumption specifics (SFC) by 20% to 25% and increase the power to weight ratio by up to 40% over current engines in that power class.

14. The Pratt & Whitney ST-9 demonstrator engine has two high pressure ratio centrifugal compressors, an atomizing annular reverse flow combustor, and a two-stage cooled high pressure turbine.

15. The General Electric GE-12 demonstrator engine has a five stage axial and one stage high pressure ratio centrifugal compressor, a vaporizing annular flow combustor, and a two-stage cooled high pressure turbine. General Electric was recently selected to develop the T700-GE-700, which is a direct derivative of the GE-12 demonstrator engine.

In addition to the fifteen technology demonstrators outlined above, there are several DoD prototype (advanced) engine developments which are outlined below:

1. Garrett's ATF-3 Engine (XF-104)

The Garrett ATF-3 engine is a three spool turbofan engine in the 4,000 lb class. This engine development started as a commercial venture. The military picked up the ATF-3 development at a point where some measure of mechanical integrity had been achieved to conduct extended development testing and qualification. By this means the Government capitalized on large commercial investment to have a qualified engine for future military applications. This engine configuration is expected to have a lower noise level than contemporary engines of the same thrust level. Additional acoustic treatment would further reduce its noise level.

2. Medium STOL Transport (MST) Engine Development

A new program is being initiated for engine development for a propulsion system suitable for use in an MST aircraft system. The engine is in the 25,000 lb thrust class and will also be applicable to other future subsonic transport or support aircraft. Recent activities in the STOL transport area have clearly highlighted the need for and advantages of obtaining a new propulsion. This new propulsion will provide significant improvements in engine performance, thrust/weight, exhaust emissions reduction, simplicity and maintainability compared to current available engines. In addition, the untreated noise characteristics of this engine are specified to be comparable to the untreated noise levels of current modern turbofan engines scaled to the same thrust size. These improvements will allow a Medium STOL Transport aircraft to have significant improved operating economics and being capable of FAA certification.

3. YJ101 Engine Prototype Development

A new program has been initiated for the development and flight clearance of the General Electric Company's YJ101-GE-100 engine. The engine is being developed to provide a candidate engine in the 14,000 lb thrust class for the Air Force lightweight prototype programs. This engine has also applications for a trainer aircraft, high altitude RPV's, foreign sales such as replacement for the F-5 aircraft and others.

B. Aircraft Propulsion Subsystem Integration Program (APSI)

The objective of this program is to assure propulsion system and airframe compatibility and permit the attainment of advanced performance objectives in future aeronautical systems. The scope of this program includes the development of advanced system-responsive components related to inlets, fans, power turbines, augmentors, controls, and exhaust nozzles; the overall integration of these components with the basic advanced turbine engine gas generator; and definition of improved inlet/engine/exhaust system installation design criteria and integration techniques.

The past APSI effort provided (1) a numerical definition and categorization of inlet/engine distortion characteristics expected from present and future high performance system applications; (2) established a technology baseline from which future transient engine accommodation control system can be designed which will automatically modulate stability margin of a propulsion system for improved transient response to increased levels of flow distortion during all flight conditions; and most importantly (3) established development

timing, procedures, techniques, and criteria for assessing inlet/engine stability, that was used as a baseline for evaluation of the F-15 and B-1 Programs.

The current APSI program includes the following:

(1) The objective of the Advanced Fan Aerodynamics program is to develop the aerodynamic technology necessary to operate turbine engine fans at very high tip speeds; to determine payoffs and material requirements and to demonstrate operation at simulated high tip speed. Based on recent successful single stage rotating fan cascade rig tests, the effort will encompass fabrication and two stage fan demonstration to establish stability and performance characteristics of these high tip speed aerodynamics under multi-stage conditions.

(2) The Composite Applications program consists of two materials efforts. Aero and environmental test and evaluation of Borsic Aluminum and Boron Polyimide composite fan components in the F-15/F-100 engine fan rig will be conducted. Also under a second program composite blades will be designed, fabricated rig and engine tested for ultimate incorporation in a test aircraft (F4C) to establish the durability characteristics under real flight conditions. The blades will be manufactured using low cost fabrication techniques.

(3) The objective of the Applied High Temperature Technology program is to integrate new high temperature turbine materials, such as Columbium and TD Cobalt alloys, into advanced turbine designs to minimize cooling flow and efficiency penalties associated with operation at high gas temperatures. The effort will include the completion of heat transfer cascade tests and initiation of an optimized vane material/cooling scheme design. This design should reduce cost significantly and increase life.

(4) The Fan-Low Pressure Turbine Development program is directed to providing an advanced turbofan technology base for future aircraft systems. Multi-stage variable geometry composite fan and high loaded LP turbines will be designed, fabricated and tested. This hardware will be directly compatible with the ATEGG gas generator hardware and advanced control concepts to provide a follow-on technology demonstrator engine test vehicle to allow efficient and effective demonstration of the critical propulsion technologies for the transonic/supersonic class of system. This is a two-contractor effort to ensure a broad base of technology in this critical area and to allow alternate approaches to reduce risk. Follow-on effort will include completion of initial engine definition, performance

simulation, control analysis, aeromechanical tests and design efforts, and initiation of multi-stage fan and L.P. turbine fabrication.

(5) The objective of the Engine/Exhaust System Integration program is to develop improved methods for engine cycle and exhaust system evaluation and selection to ensure realistic performance prediction and achievement in future aircraft/propulsion system installations. In order to accomplish this objective, two contractual efforts are underway. The first effort (Development Analysis) takes a primarily analytical approach to the problem. The program consists of efforts to determine the relative effects of engine cycle parameters on installed exhaust system performance, the identification of required airframe/propulsion system time-phased interface development requirements and analysis of performance error factors, assessment of test techniques and bookkeeping procedures for determining installed performance through model testing, and the development of a flexible analytical technique which is capable of accurately predicting installed performance of various turbopropulsion installations. The second effort (Empirical Assessment) approaches the problem from the windtunnel/flight correlation view. Windtunnel propulsion/airframe testing, corresponding to existing flight test data on the F-4 aircraft, will be used to provide the data necessary to develop turbojet and turbofan installed propulsion system correlation techniques. Propulsion/airframe model testing will establish improved test techniques and analysis procedures, determine the most practical scale at which aft-end drag tests can be conducted, and develop a plan for assessment of procedures. The follow-on effort will involve the step-by-step execution of the procedures for performance prediction related to advanced propulsion systems and verification of the correlation of parameters via windtunnel testing.

(6) The objective of the Multi-Mission Propulsion Simulator program is to improve integrated propulsion/aircraft performance by developing small scale engine test hardware which will allow simultaneous simulation of inlet and exhaust flow conditions during aircraft model windtunnel testing. Based on the analysis of the simulator design flexibility and hardware windtunnel feasibility demonstration, a follow-on effort will be initiated to develop the propulsion simulator into a fully integrated development test tool.

(7) An Inlet-Engine-Exhaust System Integration program will be initiated with the objective of providing a broader scope of advanced technology for integrating the airframe/propulsion system of a wide class of high performance transonic/supersonic systems. Based on current APSI/ATEGG advanced component, engine definition

and installation technology assessments, this effort will assess advanced test methods and analytical procedures to determine most effectively installed propulsion/aircraft characteristics, and develop advanced installation design criteria and guidelines. Emphasis will be on advanced balance systems providing measurement of total A/C drag increments, and inlet drag determination using these test techniques. The above program is based on the results of the following two efforts.

(8) The Airframe/Exhaust Nozzle Integration program will help determine the exhaust nozzle integration criteria needed to minimize the nozzle-aircraft aft-end interactions which increase drag and reduce range potential of advanced tactical aircraft. The program will provide the testing at AEDC of integrated nozzle/aft-end models in a complete aircraft configuration. Various nozzle spacings and aft-end interfacings will have been tested on complex force balance models, to determine installed thrust levels over a wide range of nozzle pressure ratios, area ratios, and Mach numbers.

(9) The objective of the Inlet/Airframe Integration program is to generate design criteria required for the definition of air-frame inlet combination having application to advanced tactical fighter aircraft forebody flow field tests and combined forebody-inlet tests will be completed shortly. Both steady-state and dynamic performance criteria were determined for selected configurations.

C. Engine Pollution Control

Most American built jet engines, until recently, have been prone to emit highly visible smoke trails when operated at or near take-off power. The main objection to engines smoking was potential observation by enemy aircraft during combat maneuvers. To alleviate the smoking problem, the Air Force and the Navy had investigated the use of chemical additives to lessen this smoking tendency. The additive alleviated the smoke but, in turn, since it was an organic-metallic compound, produced residues (ash) on hot parts of engines which affected the air flow and caused hot corrosion of turbine buckets. Work is continuing by the military services on the development of a fully suitable anti-smoke additive, although the probability of success appears low. Another approach to preventing turbine engine smoke is that of modification of the combustion chamber and its attendant fuel spray system. Modifications of the burner section of the J-79 engine have been underway for several years without complete success to date. The military specifications for engine procurement have been revised to assure that acceptable smoke limits will be obtained. It should be pointed out that this does not necessarily mean the production of absolutely no smoke, but rather the quantity

will be below an acceptable visual threshold measured by a standard method acceptable to both the military and civilian community. The military, together with the engine companies, have established a new smoke standard and has been issued as an SAE Standard. Considerable pressure has been brought to bear on the commercial airlines to reduce the smoke problem, especially at large airports, and many engines in the civilian fleet are in the process of being retro-fitted with "smokeless" combustors. Similar pressure has not been brought to bear on military operations but, since President Nixon's decree that the federal government would take a lead in the pollution areas, the military will follow suit to minimize this tendency of military engines. As an example, recent engine development programs, such as the Army's T-700 turboshaft intended for use in the UTTAS helicopter, require the reduction of exhaust smoke to a non-visible level.

Another undertaking in the pollution areas is the reduction of nitrogen oxides emitted by turbojet engines. Present engines emit measurable amounts of nitrogen oxides due to the temperatures produced in the combustion chamber section of the engine. Some alleviation of this problem can occur by redesign of the fuel distribution system of the combustor. Other potential means of reduction of these oxides would be by use of fuel additives or perhaps an entirely new concept of combustion chamber, namely, a catalytic combustor. The Air Force has R&D programs, which will continue, to investigate the fuel additive approach and is also planning a program to assess the advisability of using a catalytic combustion scheme. NASA is investigating NO_x reduction by means of rapid quenching of primary combustion with secondary air (a short combustor) and/or the use of water injection. Either of the above concepts would be available to commercial airlines in the event either became operationally suitable.

Perhaps the greatest problem in the pollution area, other than establishing human tolerances to pollutants, is the dynamic measurement of same. The measurement of any given pollutant under a quiescent condition is readily feasible. The measurement of pollutants issuing from the exhaust nozzle of a turbine engine at speeds near the speed of sound, and on an instantaneous basis, is extremely difficult. The Air Force has undertaken a program employing laser Raman spectroscopy to develop an instrumentation system which will identify specific pollutants, under dynamic conditions, on a real-time basis, and in a mobile "packaged" unit. The first development will be a mobile ground-based unit, and future developments may result in an airborne system. In addition to being able to identify jet engine exhaust species, such a unit could conceivably be used for assessing day by day degradation of an engine's internal condition,

or even be used for a "police" type operation which could be used to insure that aircraft operators were maintaining their engines within acceptable pollution limitations.

A Climatic Impact Assessment Program (CIAP) is currently being undertaken by several Government agencies. Under the auspices of the DoT, this program has as its goal a complete assessment of the impact of supersonic, high-altitude, aircraft operation on the atmosphere and subsequently on the entire biosphere. Air Force, NASA, and Navy participation in area of engine testing, flight emission measurements, and modeling of atmospheric physics, together with industry aid in engine configuration will enable the nation to realistically assess this problem if, in reality, it exists.

The DoD/USAF has an additional program on the Control of Noxious Emissions (CONE) wherein all the Laboratories that are participating in the various fields of noise and pollution (smoke, NO_X, etc.) are reviewed and directed so that all existing directives on environmental control are suitably addressed.

The NASA-Lewis source pollution program encompasses both analytical and experimental approaches to the understanding and evaluation of mechanisms involved in the formation of combustor pollutant emissions (CO, NO_X, and CH_X) and in the techniques involved in reducing the level of these emissions. Analytic efforts include contracts utilizing existing and modified computer programs capable of analyzing the effects of swirl on combustion stability and pollutant formation and the formation of pollutants as a function of time and distance in a combustion process. These efforts will be supported by in-house experimental programs. Other contractual efforts include an odor intensity/character study of engine exhaust gases at or near idle conditions, the investigation of combustor design modifications intended to reduce pollutant emissions at near idle conditions, and the effect of steady flow turbulence on pollutant formation. Inhouse NASA-Lewis efforts are being directed towards the investigation of techniques to reduce pollutant emissions of both primary combustors and reheat burners over the complete range of operating conditions including engine idle, takeoff and cruise. The goal of this program is to demonstrate a low pollutant combustor in an existing high bypass ratio engine. In addition to these efforts, a significant amount of effort is being applied to improving the measurement and understanding of readings involved in the analysis of combustor emissions.

The Army has established an aircraft emissions reduction program with the objectives of defining pollution abatement requirements of Army aircraft gas turbine engines and providing emissions reduction

technology to meet those requirements. The overall approach is to measure the emissions of present and advanced technology prototype Army engines, to establish, by coordination with the EPA, emission level targets, and to conduct research and exploratory development of promising reduction concepts, culminating in demonstration of compliance with the reduction requirements.

D. Noise

1. Department of Defense

a. Army:

The primary emphasis of Army acoustics efforts is in the areas of helicopter aural detection and reconnaissance/surveillance aircraft. Currently,the Army is engaged in the YO3-A Aircraft Program with Lockheed Corporation to develop a quiet reconnaissance/surveillance aircraft. After their successful Quiet Airplane Program (the Army YO3-A is a successor to the ARPA QT-2 quiet airplane) the Advanced Research Projects Agency (ARPA) sponsored the Quiet Helicopter Program. It resulted in a quiet version of the Army's OH-6A helicopter. The quiet OH-6A, nicknamed the Quiet One, has an external, overall noise level of 18-20 dB less than a standard OH-6A in a hover and 14dB less in cruise flight. The distance from a possible listener to the helicopter, when it is first heard, is therefore greatly reduced (7 to 1 reduction). In a low level approach this would give the enemy much less time to fire upon it. The acoustics research conducted under this program has indirect application to the noise abatement problem. Research efforts include quiet propellers, piston engine noise suppression techniques, aural detectability studies, and the refinement of aerodynamic noise prediction techniques. Another Army program is currently being pursued on advanced technology V/STOL propeller critical components. This program will include the design, fabrication and test of high risk, high gain components for a 2000 SHP lightweight V/STOL propeller system. Included will be: (a) the use of borsic-aluminum composite material for the blade retention system; (b) a titanium lightweight hub and (c) large diameter duplex tapered roller main bearings for hub to propeller reduction gearbox interfacing

b. Navy:

Very little acoustics work is currently on-going within the Navy. Efforts are limited to quiet propulsion studies for the TRIM aircraft (Trails and Roads Interdiction Mission) and studies related to the noise environment of current aircraft carriers.

c. Air Force:

A considerable effort is currently underway within the Air Force in the areas of Bio-acoustics, Propulsion Acoustics, Aircraft Acoustics, and Aircraft Noise Measurements. These efforts are described by organization.

(1) Air Force Office of Scientific Research

Dynamics of Flow Fields

Strategic bombardment, tactical operations, and logistic support are AF functions which require the use of high performance flight vehicles. The operation of such vehicles produces intense noise from sources associated with propulsion systems and from noise and pseudonoise sources associated with flight through the atmosphere. This noise causes degradation in human performance, reduced reliability of structural and equipment subsystems, and increased maintenance. Because of a lack of a basic understanding of the physical behavior of high intensity sound, rational noise control and avoidance is difficult. The Air Force Office of Scientific Research maintains basic research programs aimed at achieving a better understanding of aircraft noise generation processes.

(2) Air Force Flight Dynamics Laboratory

Prediction and Control of Aircraft Noise

The Air Force Flight Dynamics Laboratory is conducting exploratory and advanced development work in aircraft acoustics, including noise control within vehicle interiors and sonic fatigue. The Laboratory has an extensive capability in theoretical acoustics, data management and analysis techniques, and experimental methods. Aircraft acoustics efforts include evaluation and prediction of sound field characteristics encountered by flight vehicles; design, development, operation, calibration, and maintenance of acoustic instrumentation and data analysis systems; and aural detectability studies related to quiet reconnaissance/surveillance aircraft. The Laboratory also maintains a number of in-house facilities for acoustic research. Detailed discussion of the Flight Dynamics Laboratory programs is outlined in Section III-D in Appendix 6.

(3) Air Force 6570th Aerospace Medical Research Laboratory

Effects of Operational Noise on Air Force Personnel

Noises experienced by Air Force personnel are the most severe in existence, creating potential problems for hearing, voice communication, performance and other body functions which threaten mission accomplishment. Noises from sources such as large rocket boosters, aircraft engines and ground support equipment continue to increase in number and intensity. The primary objective is to control acoustic exposures of Air Force personnel and neighbors within safe and acceptable limits through research directed to definition of hazardous noise, determination of effects on body function and on performance, establish principles and devices to counteract adverse effects and specify exposure limits in the form of tolerance criteria to control overexposure. Major emphasis is on in-house research with minimal supplemental efforts by contract. Coordination occurs with the Army, Navy, NASA, FAA and DoT.

(4) Air Force Aero Propulsion Laboratory

(a) Propeller Technology

Significant propeller system technology advancement is an area of major importance for V/STOL and light aircraft. The propeller technology task consists of three areas: (a) lightweight propeller and propeller/gearbox development; (b) improvement of propeller aerodynamic performance and analytical prediction techniques; (c) prediction and reduction of propeller and gearbox system noise. More specifically, near term areas of concern are: decreasing propeller/gearbox system weight through the use of high strength-to-weight ratio materials and composites; improving propeller system performance through the application of cyclic pitch and variable geometry; improving basic airfoil design for optimum performance; determining accurate static thrust prediction methods; improving noise prediction techniques through improved basic noise source theory; and improving propeller noise scaling techniques and noise reduction through utilization of unique propeller designs based on noise source theory information.

(b) Propulsion Acoustics

With the advent of larger and more powerful military aircraft propulsion systems, it becomes increasingly apparent that appropriate steps must be taken to alleviate the noise problem. Engine noise levels must be reduced in order to provide a

safe working environment for ground and flight crews, to alleviate the problem of acoustically induced structural fatigue, to reduce the possibility of aural detection during combat operations, and to improve the general community environment around military air bases. In order to achieve the apparently diverging goals of low noise and high performance, continuing research efforts to develop a better understanding of the basic mechanics of noise generation are required. Further discussion is contained in Section III-D, Par D-4 (Sonic Fatigue).

The Aero Propulsion Laboratory maintains a comprehensive propulsion acoustics research and development program consisting of contracted and in-house efforts. The overall objective is to develop the technology base necessary to significantly reduce aircraft propulsion system noise with minimum associated performance and weight penalties. The work efforts under this task are directed toward two specific goals:

1. Development of quiet propulsion for reconnaissance/surveillance and special operations aircraft, and

2. Reduction of propulsion system noise to support current Government noise abatement efforts.

(5) Air Force Weapons Laboratory

Computer Noise Exposure Forecasting

The objective of this project is to review the methods in AFM 86-5, Land Use Planning with Respect to Aircraft Noise, to predict local community response to changes in noise levels resulting from Air Force aircraft operations. Future application of these new methods will allow the locating of new aircraft to bases and the controlling of other aircraft operations in a manner to minimize noise disturbances. The approach taken will be to modify the Federal Aviation Administration's computerized noise exposure forecast (NEF) technique to allow it to predict the effect on the local community of noise caused by Air Force aircraft operations. Thus far AFRL has advertised for qualified researchers and is in the final stages of completing a procurement package. Coordination is being accomplished to conduct AMRL in-house noise measurements on Air Force Aircraft in operation.

(6) Aeronautical Systems Division

A number of programs have been initiated to provide demountable and portable noise suppression equipment for use

during ground maintenance run-up operations of turbine-powered aircraft and engines on test stands. These programs will cost approximately 36 million dollars through FY74.

2. Department of Transportation (FAA)

The efforts of the Department of Transportation are divided into various programs as follows:

a. Noise Reduction and Control - Source:

The work for this program involves the investigation of the parameters that cause or influence the actual generation of noise emanating from aircraft, plus development of guidelines for changes to the engine hardware to minimize this noise. In addition, the effort will include development of equipment or devices necessary to be installed, attached, or actually built into engines of various designs to suppress that noise which is generated. Included are studies to improve techniques of noise measurement, data reduction and analysis, plus refinement of yardsticks for evaluation and rating of various levels of aircraft noise.

b. Noise Reduction and Control - Transmission Paths:

The work for this program concerns efforts to minimize the noise by proper consideration of the paths the noise takes to travel from its source to the receivers. The work will involve development of optimum safe operational procedures designed to minimize noise. The studies will cover the aircraft performance characteristics, the safety aspects of noise abatement procedures, as well as the noise exposure that results from various flight profiles and ground operations. Included are studies to improve techniques of noise measurement, data reduction and analysis, plus refinements of the yardsticks used for evaluation and rating of various levels of aircraft noise.

c. Noise Reduction and Control - Receiver (Human Response:

The work for this program concerns efforts to reduce, control, and evaluate the noise at the receiving end. The work will involve developing and refining acceptable yardsticks for evaluation and rating of various levels of aircraft noise, and the development of guidelines for planning for and control of the residual noise inherent in airplane operations.

d. Systems Analysis:

The work for this program involves a systematic study of all aspects of the aircraft noise abatement program. The individual and collective impact of the technical, economic, social, political, operational and psychological considerations of the problem are to be quantified and/or qualified for use in cost effectiveness studies relating to the selection of desirable alternative solutions. This program, in total, will supply background and support to rulemaking decisions, certification standards and procedures, operational procedures, land use guidelines, and other abatement programs.

e. Sonic Boom Generation and Propagation:

The objective of this program is to acquire additional knowledge of the fundamental factors of sonic boom generation and propagation in order to design aircraft in such a manner as to eliminate or minimize the sonic boom on the earth's surface. Subprograms provide for research in the theory of new concepts in aircraft design and make provisions for wind tunnel and other laboratory experiments. The effect of the atmospheric action on the form of the sonic boom signature is also being explored. This work involves investigation of parameters that influence the shock wave, improving methods of predictions and theoretical computation of the magnitude of sonic boom, arrangements of aircraft configuration with emphasis on exploration of nonconventional or exotic concepts; the identification of characteristics of the influence exerted on the sonic boom trace by the atmosphere under varying conditions of temperature, density, turbulence and humidity; and effect on the signature trace of man-made and natural topographical features.

f. Human Response to Sonic Boom:

The objective of this program is to more accurately determine the effects of sonic boom on the whole man. This work involves short-range and long-range investigations of the psychological, physiological, and sociological factors. The ultimate purpose is to provide definitive guidelines upon which to base engineering decisions with respect to aircraft design and appropriate information on which to base regulatory programs.

g. Animal Response to Sonic Boom:

The objective of this program is to determine short- and long-range effects of sonic boom on wild and domestic birds and animals and aquatic life forms. It includes theoretical,

laboratory, and practical "barnyard" studies on selected critical species to analyze the behavioral and reproductive effects, if any, to provide data for regulatory purposes.

h. Structural Response to Sonic Boom and Sonic Boom Instrumentation:

The objectives of this program are to determine the effects of isolated and repeated sonic booms on structures since this type of impact has not been previously considered in structural design. It includes the development of special instrumentation. New techniques for a dynamic system analysis must be developed that includes varying forms of sonic boom signature, materials, geometry, and boundary conditions. Studies will be conducted primarily through simulation and, where possible, under field conditions. This data will contribute to the knowledge needed for the engineering design of aircraft and in the regulatory process.

3. National Aeronautics and Space Administration

The largest fraction of NASA's aircraft noise abatement effort is directed toward reducing noise at the source. Source noise reduction includes basic research in jet noise, turbomachinery noise, and duct acoustics. Present efforts in jet noise research are aimed primarily at understanding the complex noise producing mechanisms in the turbulent shear mixing zones of high- and low-velocity jet streams issuing into ambient air.

Research in turbomachinery noise is directed to the interactions of blades and vanes with the turbulent wakes of adjacent stages. Other work is investigating the processes of wake development, the means for wake control, and the fluid mechanics of edgetones.

Research in duct acoustics is directed toward developing analytical techniques for predicting the noise attenuation provided by acoustically treated ducts. The analysis includes the physical size and shape of the duct, the sound frequencies and amplitudes, the duct wall acoustic impedance as a function of frequency and amplitude, and the duct flow velocities and characteristics.

A new Noise Research Facility, being constructed at Langley, will be completed and ready for useful research during the latter part of 1973. In the Noise Research Facility, provisions have been made for studying the acoustic properties of materials, and the dynamic response of structures to noise excitation. In addition, provisions have been made for evaluating materials, devices and

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techniques for noise reduction, and research will be conducted on the reactions of people to aircraft noise.

NASA's source noise reduction technology programs can be described by their application of aircraft type: subsonic, including CTOL, STOL and VTOL, and supersonic transport. Principal noise reduction activity in the past has been related to CTOL and supersonic transport noise reduction, but work in STOL noise abatement has now received additional emphasis. A major portion of NASA CTOL work has been the Experimental Quiet Engine Program.

The first acoustic tests of the CTOL Experimental Quiet Engine were completed in November 1971 with excellent results. In an unsuppressed baseline configuration the noise levels were the equivalent of at least 3 EPNdB lower than the original target of 15 to 20 PNdB below the noise level of 707/DC-8 aircraft. The Quiet Engine without nacelle suppression surpasses FAR 36 new aircraft requirements by 6 EPNdB. With suppression, the noise levels are 15 and 13 EPNdB lower than FAR 36 for takeoff and approach, respectively, of an aircraft at a gross weight of 148,000 kg. These levels are 25 to 30 EPNdB below those of current narrow-body jets.

In FY 73, the CTOL Quiet Engine test program will be completed at Lewis and will include testing of the engine with an optimized acoustic nacelle which is expected to show further improvement in acoustic performance.

Substantial progress has been made in noise technology programs since the initial CTOL Quiet Engine design decisions were made in 1969. Jet noise correlations have been improved and a firm data base for fan noise prediction has been developed. The feasibility of substantial reduction of the fan noise of the high bypass ratio engine, matched with similar reductions in jet noise, has been demonstrated. The result is that it now appears possible to design an advanced version of the CTOL Quiet Experimental Engine called CTOL Experimental Quiet Engine Mark II, which will incorporate all the advances in technology and will have a more nearly optimum trade-off between noise reduction and installed weight penalty.

Studies to seek an optimum configuration for this experimental engine are planned for FY 73. These studies will be used as a basis for selection of CTOL Quiet Engine Mark II design characteristics and to develop the necessary program planning information for an experimental engine program.

No current aircraft jet propulsion system exists today which can fulfill the STOL aircraft noise goals of 95 EPNdB at 500 feet.

NASA has initiated a program to develop the technology for propulsion components and systems meeting anticipated STOL application requirements for noise and pollution and which minimize the performance, weight, and cost penalties to achieve these requirements. The NASA Quiet STOL Propulsion Technology Program consists of three major parts: (1) support of the NASA Quiet Experimental STOL Transport Research Airplane (QUESTOL); (2) supporting Research and Technology for Quiet Clean STOL Propulsion Components and Systems; (3) Quiet Clean STOL Experimental Engine Design Studies. The QUESTOL program support effort is exploring feasible noise reductions for a TF-34 engine installation. This engine is a high bypass ratio turbofan applicable to the externally-blown-flap (EBF) configuration for the QUESTOL program.

The supporting research and technology work for quiet, clean STOL propulsion components and systems is determining the unsuppressed and suppressed noise and aerodynamic performance characteristics of fans over a range of design parameters applicable to EBF and augmentor wing STOL aircraft. System-installed performance will also be determined in wind-tunnel tests at both low and high speeds. This information will permit engine design and cycle selections to provide an optimum balance between noise reduction and performance.

The Quiet, Clean STOL Experimental Engine design studies are closely related to associated STOL aircraft system studies. The propulsion studies will establish the design characteristics and program plans for the development of one or more quiet clean STOL experimental engines.

NASA-supported aircraft studies indicate that lift-fan propulsion systems are the most promising ones for future civil VTOL aircraft. Noise considerations are crucial to the design of acceptable lift fans for commercial application, and a major decrease in noise level is required to permit the exploitation of their small field capability. The technology to accomplish the needed noise reduction is not yet in hand; this motivates much of NASA's present STOL noise work.

Research on the VTOL lift-fan noise problem is progressing at both Ames and Lewis Research Centers. Analytical and experimental lift-fan noise studies have been made and tests to measure flight characteristics of such fans have been conducted in the Ames 40x80-foot wind tunnel. A new vertical lift engine facility is under construction at Lewis and will be operational in about one year. Advanced lift-fan design concepts will be tested in the facility to establish the needed technology for VTOL noise reduction.

The viability of a future U.S. supersonic transport will depend at least on the achievement of acceptably low noise levels. NASA is continuing a basic research and technology effort on high-velocity jet mixing noise, which is the dominant noise source in a supersonic transport propulsion system. NASA is studying new nozzle concepts to reduce the thrust loss and increase the effectiveness of jet noise suppression. A flight test program is being conducted at Lewis Research Center using an F-106 aircraft as a test bed for evaluating the nozzle designs.

For the helicopter, continuing studies at the Langley and Ames Research Centers are leading to improved correlation of flow dynamics, structural dynamics and noise. These studies offer considerable promise for the design of helicopters with improved vibration and noise characteristics. Large-scale rotor tests of advanced designs are planned in the NASA rotor whirl tower and in the 40x80-foot wind tunnel.

E. Aircraft Fire Protection

The DoT/FAA and the DoD/USA/USN/USAF have been, for several years, investigating the use of "safer" fuels for aircraft. Several approaches for making a fuel "safer" have been investigated. The FAA and USN investigations have been directed towards the development and test of gelled fuels. These result in a fuel which, in the event of an aircraft crash, have much less spray and mist formation and hence are, from that standpoint, less flammable. The DoD has an interest in "safer" fuels from the standpoint of gunfire vulnerability and, to a lesser extent, from crash situations. Investigations of gels and emulsions, by the Army, have resulted in fuels with greater safety. The USN has for many years used a jet fuel with a very high flash point (140°F or above) to provide much greater safety in fuel operations aboard aircraft carriers. The development of a "safe" fuel would be of much interest to commercial airline operators, provided the material could be economically produced and utilized in aircraft without excessive modification.

The engine nacelle of jet-powered aircraft furnishes a great potential as a source of serious fires. The proximity of a plentiful supply of fuel, together with numerous potential ignition sources, requires that a system capable of detecting fires at the earliest possible moment be incorporated into the nacelle. Current practice on both military and commercial aircraft is, generally, to use either a single or dual loop overheat detection cable. This cable, when suitably heated, notifies the pilot of this overheat condition. A study has shown that the pilot's indicator for overheat is actuated 80% of the time when there is no fire. It has also

been ascertained that when a fire is present, this system has given a pilot indication only about 50% of the time. Work has been conducted by the Air Force for approximately four years on a new concept of fire detection known as the Integrated Fire and Overheat Detection System, which consists of a multiplicity of infrared, ultraviolet, and overheat sensors, and a nominal number of these sensors would be about four. The output of the sensors is channeled to a small logic network and thence to a pilot's readout. Due to the location of the sensors and the ability of the logic network to differentiate malfunctioning sensors and a fire, the pilot indicator will be energized and read out in an alpha-numeric display the specific signal of FIRE or FAIL, thus affording the pilot the opportunity to go to the emergency mode and still have a degree of assurance that he still has a workable fire detection system. This system has now completed prototype development and is under flight test in C-135 and Convair 880 aircraft. It is projected that essentially all commercial aircraft, at some future date, will utilize this system or some variation thereof. The U. S. SST was planning on using a variation of such a fire detection system and the Concorde utilizes many elements of this concept.

The problem of fire detection in inhabited spaces, such as cockpits and freight compartments of cargo aircraft or in spacecraft, also poses a problem. A recent USAF development on a new concept of smoke detection has been developed by a USAF employee which utilizes specific back scattering of light. This unit is nearly 20 times as sensitive as present smoke detectors. Its incorporation into future spacecraft, military cargo aircraft, and commercial aircraft, is almost a certainty.

Another aspect of aircraft fire protection which has received considerable attention in the last four years is that of fire and explosion suppression. Several systems are currently in use for explosion suppression such as the freon system used in commercial aircraft fuel vent lines. Development of this unit was hastened by an incident wherein a commercial airliner was struck by lightning and subsequently destroyed by the resultant explosion. USAF combat losses in Southeast Asia were considerably reduced by the incorporation of fully packed fuel tanks containing a reticulated polyurethane foam which served well to prevent catastrophic explosions due to ground-fire projectiles. Another approach to preventing fuel tank explosions is that of inerting the tank ullage space with a non-combustible gas. Commercial systems have considered nitrogen inerting. This system, however, requires logistic support with liquid nitrogen which is not generally available world-wide to the military services. The USAF is also developing an on-board inert-gas generation system. Catalytic combustion and oxygen absorption

techniques are being investigated. This system has the potential of lighter weight per tank volume protected than does either the packed foam or nitrogen system. When fully developed, either of these concepts would well be considered by commercial operators. The NASA has had considerable success in the development of flame retardant foams and intumescent coatings and paints. Intumescent materials expand many fold upon the application of heat, thus forming an effective heat transfer barrier which reduces the damage potential to structures of intense fires. This material, too, will undoubtedly find many applications in engine nacelles of commercial and military aircraft.

F. On-Board Power Systems

The military services have been investigating a new concept in power generation known as VSCF which is an acronym for Variable Speed Constant Frequency. The Navy and the Air Force have been alternately funding this program for approximately ten years. The 3-phase system, previously discussed in Section II, requires the use of a constant speed drive to maintain constant frequency output with varying engine speed. In the VSCF concept the alternator is driven at engine speed (or some multiple thereof) and therefore produces a frequency output which varies with engine speed. This variable frequency output then is put through a synthesizer which first dissects the generator output and then reconstitutes it at a constant 400 cycles per second frequency. Recent developments in higher power solid state devices, together with better generator designs, have now made this concept competitive with the 3-phase/CSD devices. It is interesting to note that the SST had planned to use the VSCF generating system. Since the demise of the SST, arrangements have been made with Boeing, through the Department of Transportation, to run tests on the VSCF hardware, hopefully to the 10,000 hour point. The B-1 production is considering the use of VSCF. It can be seen that the VSCF concept was developed to a point with military funding, thence transferred to Government civil funding, and with the advent of translation to the B-1, would be transitioned back to military funding.

The development of on-board power systems, as outlined in Section II, was noted as having considerable development in the generation area. The switch gear, however, remained quite similar in all aircraft in that the generated current was run through the crew compartment where switches or circuit breakers were available, and thence routed to the power using equipment. The necessity for many thousands of feet of heavy copper wiring results from this practice. A new concept of power switching will be the use of solid state switch gear located immediately adjacent to the device to be powered.

This solid state switch, in turn, is "triggered" by a relatively minute voltage which can be supplied through a considerably smaller conductor and thus results in a large weight (copper) savings. Another advantage of this system is the potential for multiplexing which is a concept wherein several signals can be transmitted by a single wiring system by rapid and alternate insertion of these signals in a preprogrammed sequence and subsequently decoding them for use by various units. Additional features of the solid state switch gear are many; faults can be detected and the current shut off in a few or even a single cycle of power, since the wires are small a redundant system may be used to enhance survivability or increase reliability, and the entire system can be routed through a preprogrammed computer to provide sequencing functions and even self-checkout. The B-1 aircraft will use this multiplexing concept but will retain the electromechanical switch gear. Growth variations of the B-1 and other military aircraft, as well as civilian aircraft of the future, will undoubtedly use solid state switch gear after it has been proven by the military.

SECTION IV

SUMMARY

Throughout the history of aviation, propulsion has been the pacing sub-system in the development of aircraft with increased capability. The development of the high-output reciprocating engines of the World War II era enabled the Allied nations to secure air supremacy. These engines, produced by a highly Government subsidized industry, were utilized in commercial aircraft in the decade following World War II. The turbojet engine, with its variations of turbofan and turboshaft types, was spawned in the World War II era. Its development, up to the mid 1960's, was totally financed by the military, or by profits derived from military sales. With the advent of turbine powered commercial aircraft, engines developed by the military, or minor variations thereof, were adopted for this use. Many persons have observed that Government development efforts have led to virtually every major advance in aircraft (jet) engines, both military and civil.

Due to the Government methodology of jet engine development, a firm technology base on advanced engine components, together with frequent "demonstrator" engines has been established. From this building block approach, engine developments for specific aircraft have been, and will continue to be, rapidly executed with large savings of both cost and time.

The Government funded programs on propulsion technology, along with developments in allied fields (on-board power, fuels and lubricants, etc.) are expected to fully provide civil aviation with a complete base of technology meeting nearly all of their future propulsion needs; for example, the NASA studies on propulsion requirements for an Advanced Technology Transport (ATT) as envisioned for CTOL operations in the late 1970's. It should be noted that "propulsion" is not of necessity limited to aircraft. Government developments on turbo-shaft engines, for instance, would be equally applicable, or adaptable, to motor vehicles. Programs on fuel cells can be used in ground power stations, and battery developments would be applicable to non-polluting autos. In the propulsion and power area, no divergence in military and civil technology needs are foreseen, and the contributions from Government R&D can be expected to continue to be great.

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APPENDIX 2

METEOROLOGY

JOINT DoD-NASA-DoT

"R&D CONTRIBUTIONS TO AVIATION PROGRESS"

(RADCAP) STUDY

MAJOR JAMES B. GEBHARD
ROBERT E. DEAN (ALTERNATE)

USAF/AFSC (ASD/WE)
PANEL CHAIRMAN

AUGUST 1972

METEOROLOGY

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SECTION I

INTRODUCTION

Meteorological research and development is probably the least understood or appreciated scientific endeavor that has made the U.S. civil air transport industry, during the past 50 years, the dominant force that it is in today's free world. The fact is inescapable that this industry has benefited immeasurably from meteorological R&D efforts funded by several governmental agencies including the Department of Commerce (DoC), the Department of Defense (DoD), the Department of Transportation (DoT), the National Aeronautics and Space Administration (NASA) and each of their appropriate organizational predecessors. Knowledge of weather is essential for the safe and efficient development and operational employment of aircraft. Since the mid 1920's, with the genesis of the first modern United States Standard Atmosphere, to the near future, with the advent of fog dispersal at air terminals, these agencies continually contribute to aviation's progress. Either independently or jointly, they have spent, or plan to spend, hundreds of millions of dollars on a multitude of programs. These programs benefit civil aviation, either directly or indirectly, and help to insure the safe, efficient, and economical employment and production of aircraft. In the sections of this appendix that follow, significant contributions to aviation by meteorology in several general areas include:

- Weather observing and forecasting.
- Weather data dissemination.
- Weather equipment.
- Weather data processing by electronic computers.
- Application of weather information and computers to provide such services as computer flight planning for modern day aircraft
- Atmospheric pollution.

Significant advances in meteorology can be credited to U. S. military programs, to non-military programs, and to joint military/non-military programs. Consequently, this appendix includes sections on Military (DoD), Civil (DoC, DoT, and NASA), and Joint Military/Civil Advances in meteorological R&D.

SECTION II

SIGNIFICANT ADVANCES SINCE 1925

The Department of Defense (DoD) is charged with the responsibility to develop and operate various weapon systems to perform a key role in ensuring national security. The Department of Commerce (DoC) has the responsibility to provide numerous weather services to a host of users, nationally and internationally. The Department of Transportation's (DoT) responsibilities include supporting and regulating all elements of civil aviation systems. The National Aeronautics and Space Administration's (NASA) charter includes an obligation to provide aeronautical research and technology for all aviation systems. As a consequence of heavily funded efforts by all of these agencies, several industries, including the civil aviation industry, have accrued several significant benefits. In the following sections, some of the significant efforts that have benefited the civil aviation industry as a result of meteorological R&D programs by DoC, DoD, DoT, and NASA are identified. These R&D programs include:

- Vertical Sounding Equipment.
- Aerial Weather Reconnaissance.
- Weather Radar.
- Severe Storm Forecasting.
- Weather Facsimile.
- Environmental Data Buoys.
- Automated Weather Network.
- Computer Flight Plans.
- High Altitude Radiation Environment Studies.
- Weather Satellites.
- Wake Turbulence.
- Standard Atmospheres.
- Atmospheric Turbulence.
- Numerical Weather Prediction. 54

. Visibility Measurements at Airports.

For this appendix, all meteorological R&D advances by DoD are referred to as Military; all advances by DoC, DoT, and NASA are referred to as Civil.

A. Military Advances

1. Vertical Sounding Systems

Both military and civil aviation require a knowledge of the state of the atmosphere to plan and conduct their operations. In order to provide this knowledge, the meteorologist requires detailed information on the current horizontal and vertical distribution of meteorological parameters. Within the atmosphere, this information is gathered mainly through the use of vertical sounding equipment.

a. Early Development

Prior to 1936, upper-air meteorological data was obtained mainly by the U. S. Weather Bureau by large box kites and balloons. In addition, special military aircraft, assigned to weather flights, obtained upper-air data but the data was limited to the aircraft's maximum flight altitude. Starting in 1925 for example, weekday flights to an altitude of 10,000 feet to obtain weather data and to test upper-air sounding equipment began at the Naval Air Station, Anacostia. In the following year, the schedule was extended by the Navy to include weekends with the altitude being increased to 15,000 feet. This method of data collection by aircraft was slow, inaccurate, and relatively costly in both money and manpower.

In 1936 the Army, Navy, and Weather Bureau endorsed support for the National Bureau of Standards (NBS) to develop a radio meteorograph. Later renamed radiosondes, these instruments were sent aloft on free balloons to measure pressure, temperature, and humidity of the upper atmosphere and transmit the data to ground stations for use in weather forecasting and flight planning.

In 1943 the Army developed a radio theodolite (SCR-658) which, when used in conjunction with a radiosonde, provided information necessary to calculate the wind speed and direction at various altitudes through which the balloon ascended. Since that time, there have been various refinements to both the flight and ground equipment. The complete system consists of three major components:

(1) Flight equipment including meteorological sensing elements, radio transmitter, and balloon.

(2) A ground direction finder for precise angle measurements.

(3) Ground recorders or data presentation equipment.

Most individual radiosonde soundings now top-off at altitudes in excess of 100,000 feet.

b. Flow of Technology

Early developments in the field of vertical sounding systems were combined efforts of many agencies with the technology available to each. Later advances, such as Ground Meteorological Direction (GMD) equipment, were developed by the Army in 1948 and adopted by the U. S. Weather Bureau in the mid 1950's.

c. Civil Aviation Benefits

During World War II, a phenomenon of great importance to meteorology and aviation was first discovered by B-29 aircrews and military meteorologists concerned with bombing raids over Japan. This phenomenon is the jet stream, a concentrated narrow stream of strong winds in the upper atmosphere. The development of the GMD in 1948 contributed to a better understanding of the jet stream and its relationship to modern jet-powered aircraft. Secondly, the radiosonde technology, including the GMD, has direct application to weather forecasting for both military and civil aviation. Thirdly, the meteorological data obtained with the radiosonde contributes in determining aircraft performance characteristics and aircraft operating efficiencies.

d. Subsequent Developments

In the early 1960's the Army completed some major changes in the GMD-1 system which became the GMD-2. Further refinements by the Air Force of this second generation system produced the GMD-2A. Further development work by the Air Force Eastern Test Range produced the GMD-4.

e. R&D Costs

(1) NBS radiosonde in late 1930's - $200,000 (estimated).

(2) GMD-1 in 1948 - $400,000.

(3) GMD-2 early 1960's - Not available.

(4) GMD-4 in 1964 - $120,000.

2. Aerial Weather Reconnaissance

The field of aerial weather observations by trained military weather personnel has advanced from a nonexistent capability in 1941 to the present day world-wide reconnaissance system employing highly trained personnel and sophisticated equipment. This reconnaissance capability has expanded to cover tropical storms, including hurricanes and typhoons, and nuclear debris sampling. Such reconnaissance has provided invaluable weather observations and knowledge of tropical storms for improved weather forecasts and information of weather effects on aircraft.

a. Early Development

Available records reveal that probably the first written recommendation for the establishment of Army Air Corps weather reconnaissance units was contained in a memo from the Chief of the Air Corps to the Chief of the Air Staff, on 28 November 1941, which recommended that "steps be taken to organize a number of weather reconnaissance units with the required trained weather personnel." The first positive action to develop such a capability occurred with the activation of the Army Air Corps Weather Reconnaissance Squadron (Test) No. 1 under the authority of a letter from the Adjutant General dated 16 August 1942. The unit's first aircraft, a C-45, was assigned on 16 November 1942. After considering the B-24, B-25, A-28, and A-29 for use in weather reconnaissance, a few B-25's became available. After the squadron moved to Truax Field, Wisconsin, on 20 April 1943 and was equipped with nine B-25's, it provided route weather information along the North Atlantic ferry route.

Using aircraft to reconnoiter hurricanes was an idea repeatedly expressed in the 1930's. In 1941 the Weather Bureau asked the Bureau of Budget for funds to hire commercial pilots for hurricane reconnaissance. The funds were denied. The Weather Bureau was advised to solicit the support of the Army and Navy. Hurricane reconnaissance was discussed with the services in 1942 but a critical pilot shortage prevented it from becoming a reality. However, weather reconnaissance was firmly established in 1945 with the activation of two reconnaissance groups and eight Very Long Range Weather Reconnaissance Squadrons assigned to the Army's Weather Service. In June 1943 the 2078th Air Weather Reconnaissance

Squadron was activated to train replacement personnel for the reconnaissance squadrons and to conduct special research studies for the development of equipment and reconnaissance techniques. By the end of 1949, the Air Force's Air Weather Service (AWS) had one group of five weather reconnaissance squadrons manned by 454 officers, 2265 enlisted men, and equipped with 91 aircraft, which in the main were WB-29's. In August 1961, AWS reached a milestone when it was named as the single manager for all nuclear debris aerial sampling. In 1963, the Air Force developed an improved Airborne Automated Meteorological Data Collection System (AN/AMQ-19) originally used on WB-47E aircraft. As WB-47's phased out, WC-135B's entered the reconnaissance aircraft inventory with an updated collection system, the AN/AMQ-25. By mid 1965, AWS had the nucleus of its present day fleet of weather reconnaissance aircraft.

b. Flow of Technology

As aerial weather reconnaissance increased in volume and versatility, increased knowledge of the atmosphere resulted. For instance, the technique of computing a hurricane's maximum surface wind through measurements of the minimum sea level pressure originated within AWS. Weather reconnaissance technology was interchanged within DoD and with other governmental agencies, the academic community, and the private sector by numerous published documents, scientific exchange meetings, and contractual negotiations.

c. Civil Aviation Benefits

Airborne weather reconnaissance over remote, e.g., Arctic and ocean, regions provides accurate and timely atmospheric observations for use in preparing forecasts. Of prime importance is the utilization of these forecasts not only for routine flight winds but mainly for the identification and avoidance of all hazardous flight conditions. Also, airborne weather reconnaissance provides the aeronautical engineer with critical weather data for use in aircraft structural design. The data provides information on the interaction of the airframe under various types of atmospheric conditions. This type of data is important to aeronautical engineers who are concerned with the structural integrity of aircraft and, subsequently, the comfort and safety of aircrews and passengers.

d. Subsequent Development

No significant subsequent development is known. However, planned R&D efforts, which are described in Section III, will significantly upgrade the capability of AWS to conduct tropical storm and other weather reconnaissance. This improved capability will be provided through use of an integrated system comprising

state-of-the-art sensors, automatic data processing, and improved data transmission facilities.

e. R&D Costs

No R&D costs were available to the Study Group. However, the Airborne Weather Reconnaissance System, described in Section III of this appendix, will require an estimated 12 million dollars in R&D money (converted to an FY-73 base).

3. Weather Radar

Through the use of ground-based weather radar, the meteorologist has acquired a unique method of observing atmospheric phenomena. Subject to certain restrictions, the variety of information presently available to weather observers and forecasters by means of ground radar observations includes the instantaneous location of precipitation over thousands of square miles and at all altitudes, direction and speed of the precipitation movement, information concerning the intensity of precipitation, heights of cloud bases and tops, approximate height of the freezing level, position-direction-speed of hurricanes and typhoons, upper level wind data, and turbulence within precipitation areas. Throughout the past 20 to 30 years, ground-based weather radar has provided invaluable real-time weather information for both military and civil aviation.

a. Early Development

In the early 1920's, radar waves (electromagnetic radiation with wavelengths of about 1/2 to 200 centimeters) were observed to reflect from trees, buildings, and other surfaces in the same manner as light waves (wavelengths about 2 million times shorter). About 1940, it became evident that operational radar systems could be constructed with wavelengths near 20 centimeters and shorter. Before these systems were completely operational, J.W. Ryde of the General Electric Laboratories, Ltd. in England made a study to determine if the performance of such radar systems would be affected by precipitation. This information was necessary in order to determine whether aircraft could escape microwave radar detection by flying in clouds, rain, snow, and dust and sand storms. Ryde's calculations indicated that microwave radars would receive echoes (radar energy returned from a target) from precipitation, and the results he obtained concerning the relative signal strengths of precipitation echoes and aircraft echoes were later shown to be quite accurate. About three months after he had completed the essential parts of his calculations, the first radar-detected storm (a thunderstorm from which hail was observed to fall) was reported

on 20 February 1941 in England. At about the same time a like phenomenon was also observed at the Radiation Laboratories of the Massachusetts Institute of Technology in the United States.

During World War II, radar systems that were useful for storm-detection purposes were limited in number and most of these were assigned to high priority programs involving aircraft detection. In addition, only a few individuals were aware of the discovery or appreciated the potentialities of this observational technique. Consequently, exploitation of radars for weather detection progressed slowly.

b. Flow of Technology

After World War II, several agencies in different countries initiated research programs in the field of radar storm-detection. Due to the wealth of surplus radar and electronics equipment, and an intense interest in the subject by persons skilled in meteorology, mathematics, physics, aviation, and electronics, rapid progress resulted. However, the lag between the initial efforts by the military to eventual use by the U.S. Weather Bureau is estimated to be approximately 10 years.

c. Benefits to Civil Aviation

Civil aviation accrued all the experience, techniques, and knowledge of the military R&D efforts during World War II and the years that followed. Certain airborne radars, especially the AN/APQ-13, were modified for weather detection purposes. The first known ground-based operational use of the AN/APQ-13 to detect weather was in 1944 on an island in the Gulf of Panama. The set was used by the Air Corps, on at least one occasion, to locate and track rain-bearing clouds. Eventually the APQ-13 was installed at approximately 100 locations throughout the United States. Most U.S. Air Force bases in the late 1940's and early 1950's were equipped with APQ-13's (see Appendix 3, page 18, 1944-1953); U.S. Weather Bureau stations used the WSR-1 and -3's. The Air Force, Navy, and U.S. Weather Bure using such modified World War II radar equipment, obtained ra weather observations throughout the United States and at mil ry bases overseas. These observations included data on:

(1) Instantaneous location of all precipitation over several thousand square miles horizontally and at all altitudes from a single observing station.

(2) Direction and speed of precipitation movement.

(3) Qualitative information concerning the intensity of precipitation.

(4) Heights of cloud bases and tops.

(5) Approximate height of the freezing level.

(6) Information as to whether or not certain storms are thunderstorms.

(7) Position, direction, and speed of hurricanes.

(8) Upper-level wind data to high altitudes, with great accuracy and under adverse conditions of visibility and precipitation.

(9) Turbulence within precipitation.

(10) Qualitative information regarding water-vapor and temperature distribution in the vertical.

The above information assisted greatly in assuring the safe, efficient, and economical operational employment of scheduled air carriers, as well as military aircraft, for storm avoidance and penetration.

d. <u>Subsequent Development</u>

Prior to 1948, no ground-based radar equipment had been designed specifically for weather detection purposes. The potential of such a radar resulted in the development of the first-generation weather radar set for the Air Force Weather Service by the U. S. Army's Evans Signal Engineering Laboratory at Belmar, New Jersey. The Laboratory established a special Radar Weather Section; it was this section that developed the AN/CPS-9, the first weather radar. Three development models were produced by the Raytheon Manufacturing Company, Waltham, Massachusetts. These sets were tested at the Signal Corps Laboratory and service tested by the Air Proving Ground Center of the U. S. Air Force. The radar set was accepted by the U. S. Air Force Air Weather Service and approximately 50 sets were produced by Raytheon incorporating certain refinements resulting from the extensive tests conducted on the experimental models.

In 1959 the U. S. Weather Bureau began operational use of the

WSR-57 which incorporated certain refinements due to the experience gained by use of the AN/CPS-9.

Responding to specific requirements of the Army, Navy, and Air Force, DoD initiated developmental efforts during the 1960's and 1971 to improve weather detection radars. As a result, the Army developed the TPS-41, a mobile radar which can be moved seasonally to specified geographical areas to observe hazardous storms; the Navy's Bureau of Aeronautics and Naval Weapons developed the FPS-68, 81, and 106, "fixed" radars, i.e., radars installed permanently at a given location; and the Air Force developed the FPS-77, a "fixed" radar to replace the obsolescent CPS-9. These radars provide more definitive, real-time weather observations that are used routinely not only by military operators but also by commercial and private operators as an aid in conducting safe air operations.

e. R&D Costs

Year	Agency	Radar Set	Millions of Dollars
1948	Army	CPS-9	2.0
1958	Navy	FPS-68	0.2
1958	Navy	FPS-81	Minimal
1959	Weather Bureau	WSR-57	1.0 (estimated)
1968	Air Force	FPS-77	0.5
1969	Navy	FPS-106	Minimal
1971	Army	TPS-41	2.5

4. Severe Storm Forecasting

After viewing the destruction caused by a tornado which crossed Tinker AFB one day in the late 1940's, two Air Force meteorologists decided to develop severe weather forecasting techniques. These would permit adequate warning of an impending severe storm so that suitable protective actions could be taken. These two meteorologists (Miller and Fawbush) developed forecasting techniques which were gradually refined and expanded into a highly accurate forecasting capability. These techniques are still in use today.

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a. Early Developments

The original forecasting techniques developed in the late 1940's permitted severe weather warnings to be disseminated by teletype for only a small area (Kansas and Oklahoma) of the U. S. As the techniques were refined, and as additional meteorological data became available, the forecast area was increased to include the entire midwest. In January 1951, the Military Weather Warning Center at Tinker AFB, Oklahoma, was given the responsibility for severe weather warning service for all military installations in the U. S. In late 1951, it also became apparent that some type of severe weather warning service was required for civilian use. Thus, the U. S. Weather Bureau commenced operational service from Washington, D. C. In early 1953, this forecast facility was moved to Kansas City. In January 1956, the military weather warning center was moved from Tinker AFB, Oklahoma, to Kansas City where it became collocated with the civilian warning center.

b. Flow of Technology

The forecasting techniques developed by the Air Force were immediately available to the civilian community. This was especially true for the period between 1956 and 1970 when the two weather warning centers were collocated at Kansas City, Missouri.

c. Civil Aviation Benefits

The benefits to civil aviation derived from the development of severe weather forecasting techniques are completely evident. Cooperation between the military and civilian severe weather warning centers has provided a two-way flow of information and increased the reliability and accuracy of the forecasts issued by each.

d. Subsequent Development

This is a continuing effort with each of the warning centers continually upgrading their capabilities through the addition of new techniques. In February 1970, the military center was moved to Offutt AFB, Nebraska so that the computer facilities of the Air Force Global Weather Center could be utilized. This permitted the introduction of additional meteorological parameters in the various forecasting techniques. In December 1970, these techniques were updated again by adding more parameters resulting in an improved forecasting capability.

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e. R&D Costs

Developmental costs of the forecasting techniques by the Air Force are unavailable. The National Weather Service estimates that over one million dollars has been expended in development of severe weather warning techniques within their agency.

5. Weather Facsimile

The National Weather Facsimile Network in existence today was a direct result of the Air Force Air Weather Service having a requirement for the reliable and rapid dissemination of centrally produced weather maps and charts. The Air Force provided the capability to satisfy this requirement; other government and non-government agencies recognized its value and joined the dissemination system.

a. Early Development

In 1947, the Air Force took action to establish a test facsimile net among a few eastern Air Force stations with the transmitting point being located at the Joint U. S. Weather Bureau, Air Force, and Navy Analysis Center. After initial shakedown, the net was placed in operational status and expanded. By 1957, the number of Navy, Weather Bureau, and civil subscribers had greatly exceeded the number of Air Force subscribers. To meet the needs of all users, the type of charts/maps and the schedule of the facsimile network were changed by joint agreement with the Weather Bureau and Navy. Eventually, it was recognized that the Air Force was in fact providing a national meteorological service for which it had no charter. The U. S. Weather Bureau had a charter, but no facility. Therefore, plans were developed to transfer the National Facsimile Network to the Weather Bureau. Operational control was given to the Weather Bureau in 1958 with administrative and budget control passed on approximately one year later.

b. Flow of Technology

Since the facsimile net was developed by the Air Force at the Joint Air Force, Weather Bureau, and Navy Analysis Center, the technology required to disseminate weather charts and maps by facsimile was routinely available and evident to both the Weather Bureau and Navy.

c. Civil Aviation Benefits

Weather facsimile products are indispensable briefing

aids for the aviation meteorologists who are required to prepare flight forecasts for military and commercial aircrews.

d. Subsequent Development

In 1959, the Weather Bureau implemented a separate facsimile circuit to transmit area forecast charts to their offices at U. S. International Airports to provide flight documentation service to departing international flights. The Air Force has developed and is procuring a digital facsimile system which will allow transmission of weather maps and charts approximately five times faster than the current system.

e. R&D Costs

Not available.

6. Environmental Data Buoys

The Federal Plan for Marine Environmental Protection provides for DoD to support the Navy Ocean Science Program. This Naval program encompasses substantial engineering developments and a large variety of research projects in the fields of physical, chemical, and biological oceanography, marine geology, and geophysics. Although these efforts are designed to meet specific military requirements, the civilian community has acquired considerable benefit through these projects. A prime example of this research benefiting the civilian community is the development of unmanned, moored ocean platforms (buoys) which acquire and transmit marine environmental data.

a. Early Development

Initial efforts to develop data buoys were pioneered by the U. S. Navy in the early 1950's. The North Pacific Experiment, funded by the Office of Naval Research, Scripps Institute, and the Naval Air Systems Command's Naval Oceanographic/Meteorological Automatic Device (NOMAD) program, provided the technological basis for the development of the National Data Buoy System. These initial 1950 efforts saved non - military governmental agencies an unspecified amount of R&D money and years of developmental and test programs. The Navy's expertise in buoys is acknowledged to be well in advance of the expertise attributable to other civil and private sector programs.

b. Flow of Technology

The U. S. Navy's contribution to the National Data Buoy System (NDBS) during the formative years of 1965 through 1967 included assistance in the formulation of the feasibility and

requirement studies and guidance for the early development policy. The contribution has continued uninterrupted in the form of technical cross-talk, use of Navy engineering drawings, examination of Navy hardware, and the actual use of Navy facilities for contractual studies. Currently, the NDBS, directed by NOAA (originally the National Data Buoy Project directed by the U. S. Coast Guard), is the largest single developmental effort in the field of environmental data buoys.

c. Civil Aviation Benefits

When the goal of establishing networks of unmanned telemetering environmental buoys is reached, civil aviation will greatly benefit by:

(1) Improved weather analysis and forecasting over the ocean routes frequented by civil aviation.

(2) Improvements in locating important weather features such as fronts, thunderstorms, and hurricanes.

(3) Added geographical fixes, since each buoy will be equipped with a radar reflector and homing beacon.

d. Subsequent Development

By the early 1980's, environmental buoys will be in use off the east and west coasts of North America and the Central Pacific. United States leadership will undoubtedly convince other nations of the desirability of having their own buoy programs.

e. R&D Costs

The U. S. Navy Air Systems Command and the Office of Naval Research have expended $3,500,000 for the development of buoys over a period of 12 years.

NOAA budgeted $12,000,000 in FY 72 and $15,000,000 in FY 73 for NDBS.

7. Automated Weather Network (AWN)

Effective environmental support to aviation is vitally dependent upon rapid dissemination of meteorological data and products.

The manual data collection and dissemination techniques in use through the 1950's were inadequate and were rapidly falling behind the requirements of global aviation. It became apparent to the Air Weather Service (AWS) that meteorological data would have to be manipulated by automated techniques to be of maximum use. Efforts to achieve this capability were initiated.

a. Early Development

In 1963, the Manager, National Communications System, established the National Weather Communications Requirements Group to determine the weather communications requirements of all civil, military, and private customers in the United States. The Group's report of 30 November 1963 proposed a concept designated DAWNS, an acronym for Digital Automatic Weather and NOTAM System. The central idea of the proposed system was the provision of one or more high performance switching centers, concentrating at these few locations all circuit control and data handling functions. All local low speed teletype circuits for collection and/or dissemination of weather traffic would terminate at a center; the centers themselves would be interconnected with high speed data links. High volume users and suppliers of data, such as meteorological computers and gateway interfaces, could also have high speed access to the center's facilities. The military requirements stated in the USAF Specific Operational Requirement for Global Weather Communications, undated, and the civil requirements stated in FAA Memorandum, 26 October 1962, Proposed Telecommunications Communications Improvement Plan, were combined to form the basis for an integrated national system. The idea for one ground system evolved into separate but complementary civil and military systems. The military's concept developed into the Automated Weather Network (AWN) and was implemented in July 1965, with Tinker AFB, Oklahoma, as the hub of the network. The network included high speed lines to Japan, England, and the Air Force Global Weather Central.

b. Flow of Technology

AWN was the first attempt to speed the flow of environmental data through the use of communications switching computers. The Air Force pioneered the technique development for high speed exchange and low speed collection and dissemination of data. The technique was later applied to the World Meteorological Organization and national civil weather communications systems. Even today AWN is the most sophisticated weather communications system in the World.

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c. Civil Aviation Benefits

The availability of more data at an earlier time has resulted in better meteorological service. This is especially true for data from overseas. The quality of meteorological support products, such as computer flight plans (see paragraph 8 that follows) and terminal forecasts, has greatly improved.

The National Weather Service has been a subscriber to AWN data. Therefore, civil aviation, due to the availability of additional and more timely overseas data, benefited as a result of economic and safety considerations.

d. Subsequent Development

In 1971, the hub changed to Carswell AFB, Texas. Univac 1108 computers were introduced and high speed lines to the Philipines, the National Meteorological Center at Suitland, Marylan , and Navy's Fleet Weather Center at Monterey, California, were added

Continued sophistication of software is being pursued to impro customer service. Air Weather Service plans to establish a second terminal in the network in continental Europe.

e. R&D Costs

Approximately 50 man-years have been expended to develop this software capability.

8. Computer Flight Plan

Prior to 1960, weather forecasters verbally briefed aircrew members on enroute weather conditions for flight planning purposes. Wind speed and direction, temperature, clouds, and significant hazardous enroute weather conditions were presented in a hand-prepared format in written, tabular, or graphic form. Crew members then determined the various flight planning requirements such as aircraft headings, true air speed, and time enroute. With the advent of the electronic computer and automatic weather data processing techniques, arduous and time consuming conventional flight planning by manual, graphic techniques is obsolescent.

a. Early Development

The necessity to provide a pilot with the best support possible led the Air Force Air Weather Service (AWS) to pioneer, in the mid 1950's, in the development of computer flight plans (CFP).

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This pioneering effort can be traced to Dr. Robert D. Fletcher, who retired as the Chief Scientist of AWS on 30 June 1972. Actually, Air Force efforts predate the computers. In the early 1950's manual, graphic techniques were developed to prepare minimum-time flight plans for transoceanic operations. When numerical weather prediction reached an operational state in the mid 1950's, the AWS began the development of CFP's at the Joint (Air Force, Navy, and Weather Bureau) Numerical Weather Prediction facility, Suitland, Maryland, utilizing computer outputs from numerical weather prediction models. The first operational CFP was produced in May 1959 for the support of transatlantic crossings by C-118 aircraft. The CFP program has been continuously expanded and improved, and by 1964 several thousand flight plans were prepared monthly, especially for jet-level aircraft. In August 1970, the Air Force's CFP center moved from Suitland to the Air Force Global Weather Central (AFGWC) located at Offutt AFB, Nebraska. With the availability of greater computer resources at AFGWC and the accessibility to the AFGWC automated data base, further significant improvements to the computer flight plan were made. A pilot can now order from AFGWC a flight plan, tailored for his particular aircraft, at a specific altitude and along one of several thousand global tracks. The flight plan can be delivered to him at a location he designates such as U. S. Embassy Office, an Air Force base, or, under certain circumstances, the operations office of a civilian airline. These computer flight plans contain information on enroute significant weather, destination and alternate terminal forecasts, navigational data, and fuel requirements. A CFP can be produced in five seconds and delivered to the requestor in one hour. Eventually, this system will be expanded to provide the optimum route/profile selection, more details on enroute weather, and flight level temperatures.

b. Flow of Technology

The computer flight plan technology developed under AWS leadership eventually channeled to governmental and private sectors. Several airlines implemented a semi-automated flight plan capability in the early 1960's. In addition, the technology that enabled the National Weather Service to provide wind forecasts in computer digestible format in early 1967 enabled a number of airlines to change to computer flight plans.

c. Civil Aviation Benefits

Hundreds of man years by AWS personnel were expended to develop this capability. Therefore, the Air Force-developed computer flight plan techniques required only modifications by civil airlines to meet their operational requirements. Computer flight

plans are extensively used in aviation today and are increasing each year. For example, the National Weather Service provides upper-air wind and temperature forecasts in digital form, computer-to-computer, for computer flight planning to 13 direct processors who, in turn, serve about 150 customers including airlines and other aviation users.

d. Subsequent Development

The AWS is continuing the development of computer flight plans. Eventually, the system will be expanded to provide the optimum route/profile selection, more details on enroute weather conditions, and flight level temperatures. The FAA in its March 1971 National Aviation System Policy Summary stated that one of its tentative goals is to satisfy 90% of the average pilot's briefing and flight plan requirements through automated means.

e. R&D Costs

Available records did not provide cost data. However, hundreds of Air Weather Service man-years and hundreds of hours of computer time were required to develop this advance in aviation's progress. An estimate of the man-hour and computer costs for this developmental effort is 30 million dollars.

B. Civil Advances

1. High Altitude Radiation Environment Studies (HARES)

Since 1965, Air Weather Service (AWS) actively participated in a high altitude radiation study sponsored by FAA and NASA. The purpose of the project was to determine the effect high altitude radiation would have on aircrews and passengers aboard civilian supersonic transport (SST) and crew members aboard military, high altitude aircraft and space vehicles. High altitude radiation orginates from galactic and solar sources and could have possible adverse affects on aircrews and passengers flying at these altitudes.

a. Early Development

HARES was conceived by FAA early in 1965. In July 1965, FAA, NASA, and the Air Force Special Weapons Center requested, through Air Force Headquarters, that AWS WB-57F's fly HARES missions. Air Force requested that AWS participate. AWS was interested in the project since it would give AWS practice in forecasting solar storms and would produce a data base that would be valuable for forecasting radiation areas where high altitude Air Force aircraft were operating. Initially, AWS flew HARES missions on a non-interference basis from

Kirtland AFB, N. M.; Eielson AFB, Alaska; Albrook AFB, Canal Zone; and East Sale RAAFB, Australia. These early missions were flown by placing FAA's equipment, i.e., the Geiger counter, tissue equivalent ion sensor, and the linear energy transfer sensor equipment, onboard WB-57's flying other missions. Late in 1967, FAA requested that aircraft be dedicated to HARES. AWS agreed and gave the project the code name Cold Flare. AWS began full time Cold Flare operations from Eielson AFB, Alaska, in August 1968. From August 1968 until the termination of the project in June 1971, the WB-57F's supporting Cold Flare flew 2636 hours.

b. Flow of Technology

The data gathered by the AWS WB-57F fleet in the radiation environment near the polar areas has confirmed previously obtained data; the data will allow scientists to determine the effects of solar radiation on aircrews and passengers at high altitudes. As a result of radiation studies and research such as HARES, DoC, through the Space Environment Laboratory of the National Oceanic and Atmospheric Administration, has been issuing radiation level predictions since 1968. The predictions are issued once a day for a 30 hour period.

c. Civil Aviation Benefits

The data gathered by WB-57F's will have both military and civilian applications. Both military and civilian aviation authorities will be able to use the data to develop regulations on aircrew duty-time at high altitudes and regulations establishing radiation protection standards aboard aircraft (including the SST) flying at high altitudes. While there are still many uncertainties in the problem of radiation hazards to SST passengers and crews, it appears that the galactic component of cosmic radiation at SST altitudes is not a problem in itself, but forms a background upon which the solar flare component is superimposed. The International Civil Aviation Organization envisions that the DoC radiation predictions will be used eventually for rerouting SST aircraft, or for advising SST aircrews to descend to a lower flight altitude to avoid radiation hazards.

d. Subsequent Development

The analysis of the collected data is continuing in order to develop regulations on aircrew duty-times and radiation protection standards.

e. R&D Costs

AWS estimates that 2636 hours of flying time were

expended in support of the data gathering effort at a cost of $2,791,796. In addition, AWS utilized weather reconnaissance aircraft on numerous occasions to airlift personnel to and from Eielson AFB, Alaska, in support of this project. DoC estimates it has expended $12,000,000 on radiation efforts; NASA estimates $900,000; and FAA costs are unknown.

2. Weather Satellites

Today, everyone accepts intercontinental weather satellite coverage as a normal method to observe the weather and as an aid in preparing forecasts. We expect to be warned of the approach of dangerous hurricanes and to predict with reasonable certainty the type of weather along remote oceanic and polar airlanes. Weather satellites are the latest and most advanced tools available to meteorologists to provide such information.

a. Early Development

On 8 May 1946, the Chief of Naval Operations requested the Bureau of Aviation to begin preliminary studies for the use of earth satellite vehicles which would contribute to the advancements in guided missiles, communications, meteorology, and other technical disciplines with military applications. In 1949, the RAND Corporation corresponded with AWS concerning RAND's initial feasibility studies for the utility of an earth circling space ship or satellite for weather observations. Through these initial studies, and the increasing need within the military and civilian aviation agencies for global weather data, the seed for the development of satellite meteorology was planted.

DoD was responsible for the initial R&D of the Television Infrared Observation Satellite (TIROS) Program. During the 1955-58 period, the Army Signal Corps spent over one million R&D dollars developing improved methods for weather satellite imagery. These studies identified the methods for data assimilation, data display, remote sensing, and future applications. The responsibility for R&D on weather satellites was transferred to NACA in 1958. In the late-1950's and early 1960's, NACA/NASA contributed significantly to weather satellite developments. These efforts are outlined in a NASA publication, NASA SP-96, Significant Achievements in Satellite Meteorology, 1958-1964. During the late 1950's, a Joint Meteorological Satellite Advisory Committee was formed consisting of military and civilian representatives. The early TIROS weather satellites were designated as R&D platforms for later operational DoC requirements. Support assistance and separate R&D continued within DoD. This included application research by the Air Force Cambridge Research Laboratories and technique development by the Air Weather Service.

On 1 April 1960, TIROS I, the first R&D weather satellite, was launched and a new era of meteorological observation began. Since then, the science of satellite meteorology has developed rapidly. The academic community now includes satellite meteorology as a major course of instruction in colleges and universities. The initial studies developed by DoC, DoD, and NASA have provided the basic techniques for the science of satellite meteorology. Significant achievements include defining the severity of major storms, severe storm locations, frontal locations, jet stream positions, remote area weather observations, and vertical atmospheric profiles.

Since 1960, twenty-two meteorological satellites have been launched with only one failure. Benefits obtained from early identification and warning of hurricanes alone have provided payoffs far above the cost of the development of these satellites. In August 1969, Hurricane Camille, described as one of the greatest storms in recorded history to hit North America, swept across the Southeast U. S. During this great hurricane, it is estimated that more than 50,000 people were evacuated and hundreds of lives were saved by effective warnings and community and individual emergency plans. Damage prevention by the safe evacuation and timely protection of aircraft within the affected geographical regions of Camille represents a vast unrecorded monetary savings.

b. Flow of Technology

DoD's initial efforts in identifying the potential use of weather satellites was a significant contribution to the development of this advance. However, it was the policy, managerial systems, and technical competence, developed during the 1960's by NASA and DoD, that enabled the United States to produce superior meteorological satellites. Nevertheless, continued refinement and research exists at different levels within DoC, DoD, DoT, and NASA. These efforts are generally tailored to specific responsibilities, i.e., military applications, earth resources, pollution measurements, and cloud climatology.

c. Civil Aviation Benefits

Civil aviation in the 1970's and beyond requires accurate weather information for extended flights at greater speed under critical time schedules and fuel limitations. Congested airways and crowded terminals further compound the requirement for accurate weather forecasts for aircraft operations. Weather satellites provide global observations, especially over the polar and ocean regions, that assist in locating storm areas that otherwise may not be detected. As a consequence, weather satellite observations provide aviation meteorologists with significant weather data that subsequently enables aircrews to plan safe and economical flight operations.

d. Subsequent Development

NASA has the responsibility for current and future R&D efforts to develop improved weather satellites. NASA has been tasked to develop and procure new spacecraft and meteorological sensors and to provide launch and tracking services. NASA has three specific satellite programs:

(1) The Improved TIROS Operational Satellite (ITOS) Program that involves the development, procurement, testing, and launching of a new generation of operational meteorological satellites.

(2) The Nimbus Program, in which new techniques and sensors are being developed using the Nimbus spacecraft as a test vehicle.

(3) The Synchronous Meteorological Satellite (SMS) Program, under which a new geostationary weather satellite is being designed to satisfy the requirements of NOAA's National Operational Meteorological Satellite System (NOMSS).

e. R&D Costs

The following R&D costs have been identified by this study for the development and application of weather satellite systems for the time period from 1958 to 1972, in millions of dollars.

AGENCY

Individual Agency Contribution		Joint Agency Contribution	
DoD	2	DoD/NASA	10
DoC	3	DoC/NASA	3
NASA	8	DoC/NASA/DoD	150
		DoC/DOT	1
		DoC/DoD	1
TOTALS	13		165

This money was used for sensor development, receiving equipment, display equipment for satellite imagery, atmospheric modeling,

vertical temperature and pressure readings, digital forecasting inputs into numerical systems, the development of new forecasting techniques, and basic atmospheric research on parameters unobtainable through earthbound observations.

3. Wake Turbulence

Wake turbulence occurs due to the violent vortices generated behind large aircraft. This phenomenon became a critical factor with the advent of the 747 and C-5 jumbo jets for flight and ground operations at aircraft terminals. Efforts to better understand, and perhaps lessen, the hazards of this phenomenon have started within governmental and private agencies.

a. Early Development

The effects of wake turbulence on commercial aviation operations became internationally highlighted by France's objections to spacing requirements for Pan American World Airways 747 flights into Paris Orly Airport. The Federal Aviation Administration standards imposed on both the 747 and C-5 prior to the 747 service into London required an accelerated testing program to satisfy international safety agreements.

The Wake Turbulence Program directed by NASA in December 1969, at Edwards AFB, involving the Air Force C-5 and B-52 aircraft were rapidly expanded. FAA, NASA, DoD, Atomic Energy Commission (AEC), and Boeing became increasingly active and began Wake Turbulence Tests at Edwards AFB, California, the AEC facility at Idaho Falls, Idaho, and at Seattle, Washington. These accelerated test programs provided our nation's basic data base for the aircrew/controller training, meteorological studies, and aircraft operational procedures.

b. Flow of Technology

It was not until the advent of jumbo jets that the effects of wing tip vortices on smaller aircraft became most apparent. Aircraft operating in and around civil airports, which are governed by FAA rules and regulations, range from the smallest type of private airplane to jumbo jets. Leadership for studies in wake turbulence by DoT, therefore, appears essential. It is important to mention that this particular area of R&D has cut across military and civilian organizational lines. Aviation meteorologists in government and industry have been active in wake turbulence studies; however, specific R&D funding has been minimal. The efforts by FAA and NASA in arranging national and international scientific meetings on wake turbulence have been especially noteworthy.

c. Civil Aviation Benefits

Wake turbulence studies benefit not only our commercial aviation fleet but also this nation's vast section of private airplane operators who suffer the most serious effects of being trapped in the grips of wake turbulence. Future studies for the dissipation of wing tip vortices will provide significant improvements in safe air traffic over the congested airlanes and terminal areas.

d. Subsequent Development

The need for additional joint R&D in wake turbulence is apparent. The scope of jumbo jet operations within the terminal area requires future wake turbulence analyses. Existing work by governmental agencies and private airlines is relatively in the initial research stage. This work includes:

(1) Taxi Operations:

(a) Exhaust wake turbulence.

(b) Ground damage potential.

(c) Effects on airfield meteorological observations.

(2) Takeoff Operations:

(a) Jet exhaust.

(b) Wing tip vortices.

(3) Landing Operations:

(a) Wake turbulence.

(b) Low level landing shears.

(c) Turbulence dissipation methods.

e. R&D Costs

The past and current research efforts on wake turbulence have been conducted mainly within the manpower resources of the military and civilian laboratories. Consequently, no R&D costs have been identified with this study.

C. Joint Military/Civil Advances

1. Standard Atmospheres

Aircraft and space vehicle design and operations require unique standards and technical data that provide realistic conditions of the properties of the envelope of air surrounding the earth. This envelope is commonly referred to as the earth's atmosphere whose chemical properties, dynamic motions, and physical processes constitute the subject matter of meteorology. During the past 50 years, approximately 30 governmental, industrial, and academic organizations that have an interest in geophysics, including meteorology, have prepared Standard Atmospheres. Standard Atmospheres include hypothetical vertical distributions of atmospheric temperature, humidity, pressure, and density. The data are essential for aircraft and space vehicle designers.

a. Early Development

The first modern Standard Atmosphere was published in the mid 1920's by the National Advisory Committee for Aeronautics (NACA). Also in the mid 1920's, a European Standard Atmosphere was produced by the International Commission for Aerial Navigation (ICAN). There were slight differences between the independently developed ICAN and NACA atmospheres. On 7 November 1952, these differences were reconciled and international uniformity was achieved through adoption by the International Civil Aviation Organization (ICAO) of a new Standard Atmosphere. This new Standard was officially accepted by NACA on 20 November 1952 and formed the basis for tables published in NACA Report 1235 entitled, Standard Atmosphere-Tables and Data for Altitudes to 65,800 Feet. The computations for these tables were carried out by the United States. Parts of the tables were independently computed by the Italian Government. Conversions from metric to English units were made in accordance with internationally adopted conversion factors.

b. Flow of Technology

These Standard Atmospheres were distributed widely, including distribution throughout the civilian aerospace industry. There was no time lag between the development of the Atmospheres and usage by the aerospace industry and civil aviation.

c. Civil Aviation Benefits

The Standard Atmospheres have been used since their genesis by the aerospace industry for aircraft design specifications,

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pressure altimeter calibration (so essential for the safe operations of aircraft in flight), and for aircraft performance characteristics such as lift, drag, and propulsion.

d. Subsequent Development

In the early and mid 1950's, there existed a rather urgent military requirement for a Standard Atmosphere extending higher than those available. In 1955, preliminary tables were prepared by the Air Force Cambridge Research Laboratories (AFCRL) for altitudes up to 1.5 million feet. These tables were immediately put to use by military designers. In 1956, the United States standardized these tables for internal use and ICAO considered this product for international standardization for altitudes to 100,000 feet. To take account of increased knowledge and more accurate determination of basic inputs to earlier developed Standard Atmospheres, AFCRL developed the U.S. Standard Atmosphere, 1962 which was adopted by the United States. AFCRL personnel played a major role on the Committee on the Extension of the Standard Atmosphere (COESA) which adopted this 1962 Atmosphere and guided its preparation. Again AFCRL provided a large part of the text that was included in this publication. In addition to Air Force sponsorship, the 1962 Atmosphere was also sponsored by NASA and by the U.S. Weather Bureau (now the National Weather Service). In 1964, the lower 100,000 feet of this 1962 Atmosphere was eventually accepted by ICAO.

In 1966, the U.S. Standard Atmosphere, 1962 was supplemented by the U.S. Standard Atmosphere Supplements, 1966. These Supplements were sponsored by the Air Force, the Environmental Science Services Administration (now the National Oceanic and Atmospheric Administration), and NASA. The Supplements provide data as functions of season, latitude, local time, properties of the sun, and geomagnetic activity. The Supplements are used extensively for aeronautical and aerospace computations and for comparison with measured values of atmospheric properties by DoC, NASA, industrial research groups, and the academic community, both nationally and internationally.

e. R&D Costs

It is estimated that AFCRL required eight man-years to prepare the initial Standard Atmospheres and Supplements. Therefore, considering all organizations involved, a minimal estimate would be 15 million dollars for the preparation of only the 1962 and 1966 editions.

2. Atmospheric Turbulence

A satisfactory treatment of turbulence in the atmosphere is undoubtedly the outstanding unsolved problem of meteorology. This is especially true of clear air turbulence (CAT, i.e., turbulence encountered by aircraft when flying through air space devoid of clouds). Every governmental agency concerned with aircraft operations has invested in research programs for the study of CAT to aid in structural design and the identification of atmospheric precursors to forecast its development. Information on separately funded programs has been exchanged with all governmental and scientific agencies. These joint and segmented efforts have in retrospect provided valuable information on aircraft designs and operations in addition to forecasting CAT. Another form of turbulence is that which is encountered within vertically developed clouds, especially thunderstorms. This type of turbulence is generally referred to as convective turbulence and is justifiably feared and avoided, whenever possible, by all aircrews due to its severity. CAT and convective turbulence are both addressed in the following sections.

a. Early Development

Severe turbulence associated with thunderstorms is considered one of the worst forms of atmospheric turbulence. Military and civil aircraft require an adverse weather capability to satisfy their respective national responsibilities. In the interest of safety, therefore, information was needed concerning the internal structure and behavior of the thunderstorms. A project was conceived in the middle 1940's to obtain information on the structure and characteristics of the thunderstorm and its associated flight hazards. This project was a result of the joint efforts by four U.S. Governmental Agencies -- Army Air Corps, Navy, National Advisory Committee for Aeronautics, and the Weather Bureau. In 1943, Dr. C. E. Buell, Chief Meteorologist of American Airlines, in a letter to the Civil Aeronautics Board, outlined such a project; the Air Transport Association vigorously supported his proposals. Weather Bureau staff members studied the program carefully and made specific suggestions on the subject. In January and March 1964, under the Chairmanship of the Weather Bureau, a committee of experts from the airlines, Army Air Corps, Navy, Civil Aeronautics Board, University of Chicago, Massachusetts Institute of Technology, Carnegie Institute, and Weather Bureau met for preliminary planning.

Congress appropriated the necessary funds to the Weather Bureau for starting the program in FY 1946; by 2 August 1945, a Director had been appointed. Two weeks later the war ended, a circumstance most fortunate for the development of what was by this time officially designated as the Thunderstorm Project. To foster a

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concerted effort on the part of all agencies, the plans for the Project were referred to the Subcommittee on Aviation Meteorology of the Air Coordinating Committee. This subcommittee appointed a working group consisting of the Army Air Corps; Office of the Chief of Naval Operations; and Dr. H. R. Byers, Project Director, University of Chicago, to draw up plans for the Project.

This Project provided the first known national scientific and experimental effort to gain knowledge on convective turbulence associated with thunderstorms. The Project produced other detailed data on the thunderstorm structure to include information on three dimensional meteorological parameters within a thunderstorm, electric fields, radar echoes, aircraft effects, and the effects on aircraft ground operations. The importance of thunderstorm turbulence was highlighted on 4 January 1972 in the Boeing 747 incident 125 miles west of Grand Isle, Louisiana. During this incident, the aircraft encountered thunderstorm-induced turbulence when the pilot was attempting to fly between two thunderstorms. The incident caused injury to 21 persons, 10 seriously.

During the 1950's, several major accidents by military and civil aircraft were directly or indirectly caused by turbulence. The civil airlines collected turbulence data on commerical aircraft routes. Military agencies, through such projects as USAF Projects Jet Stream and Cloud Trail and U.S. Navy Project Applied Research--Operational Weather Analysis (AROWA), also collected turbulence data. By the early 1960's, empirical rules had been formulated to provide guidance in CAT forecasting.

By 1964, the CAT encounter situation had increased to a point where a major effort was deemed necessary by the United States Government to determine its cause and to develop CAT sensing equipment. In the years following, efforts to locate and avoid CAT areas resulted in improving passenger/crew safety and reducing structural damage to aircraft. However, CAT is still a major concern to aviation because of the inflexibility of military operations and to civilian aviation for safe air travel.

The major DoD follow-on studies involved Projects ALLCAT and ROUGH RIDER. Project ROUGH RIDER was a joint thunderstorm research effort which began initially in 1960 under the direction of the United States Weather Bureau's National Severe Storms Laboratory (NSSL). In 1961, the Air Force Cambridge Research Laboratories (AFCRL) became an equal participant in ROUGH RIDER and continued in this role with NSSL up to the present. NSSL's main concern was to gain knowledge of the degree of severity of gust loads inside thunderstorm cells. AFCRL's main objective was to investigate the

various electrical phenomena associated with thunderstorms. The joint DoC/DoD cost of ROUGH RIDER was close to three million dollars.

The objective of the ALLCAT Program (1967-71) was to establish valid turbulence design criteria for future aircraft. The study considered layered atmospheric regions from the earth's surface to 200,000 feet. Air Force R&D costs on this program totaled 8.7 million. The wealth of scientific data is still being analyzed. Over thirty reports have been written within Air Force research organizations on ALLCAT data alone. The release of the information to civilian institutions has produced valuable information as a result of graduate level research.

In the late 1960's, DoD became involved in a national study of CAT under the National Committee for Clear Air Turbulence (NCAT). In this effort, DoD assumed responsibilities for efforts in the area of measurements, observations, and remote detection of CAT; DoC assumed responsibilities in the area of CAT forecasting.

b. Flow of Technology

The R&D efforts by all governmental agencies in atmospheric turbulence efforts and the cooperative flow of technology have been excellent. All major programs were jointly established and the benefits available to any agency desiring to pursue scientific advances. This cooperative effort has significantly increased our understanding and reduced, but not eliminated, the encounters of turbulence in aircraft operations.

c. Civil Aviation Benefits

The increased safety of passenger travel through reduced encounters with CAT has obviously provided direct benefits to civil aviation. The understanding of the mechanism of CAT, which resulted from these joint efforts, has improved meteorological forecasts. Although CAT forecasting is far from perfect, the initial effort to identify and forecast CAT's occurrence has been accomplished by the Air Force Global Weather Central.

Additional benefits on these turbulence projects include information on lightning effects on aircraft, hail damage, structural design requirements, static precipitation effects on radio communications, and aircrew/passenger hazards.

d. Subsequent Development

Budget restrictions forced the cancellation of the large NCAT program despite the continued need for this research. Nevertheless, DoT has identified a requirement for improved warning devices regarding turbulence and its avoidance at jet altitudes and speeds, and DoD still needs turbulence information for aircraft design criteria and turbulence forecasting. Funding allocations are not definitive enough to determine if these planned programs will be realized.

e. R&D Costs

The cost of the Thunderstorm Project is not known by the Study Group. The combined DoD cost on all follow-on turbulence studies including Projects Jet Stream, Cloud Trail, Navy AROWA, ROUGH RIDER, and the ALLCAT Program is estimated to be 25 to 30 million dollars.

The above projects involved inter-agency cooperation but were funded primarily by DoD. Additional programs by DoC, DoT, NASA, and private airlines also were active in the 1960 time period, the major projects being the NASA/FAA Turbulent Air Pilot Environment Research Program and Eastern Airlines research on airborne CAT sensors. The costs of these programs are unknown.

3. Numerical Weather Prediction

One key to increased cost-effectiveness in both civil and military air operations is an increased weather forecasting capability. This capability, in turn, depends on more sophisticated numerical models of atmospheric physical processes. Significant contributions in the area of numerical modeling and forecasting occurred through the Joint Numerical Weather Prediction (JNWP) Unit in Washington, D.C.

a. Early Development

Lewis F. Richardson's contribution to dynamic meteorology in the 1910-20 period provided the mathematical analysis for the "Richardson Criterion" used in turbulence studies and numerical methods for weather predictions. His early hand computational methods and his visionary statement that computers "might go perhaps ten times faster than he himself" are without a doubt one of the significant milestones worthy of special mention.

In the mid-1940's, John von Neumann, under a Navy contract, began to build an electronic computer primarily for the purpose of weather prediction. In the late-1940's, the Air Force joined this

effort; a basic capability was eventually demonstrated. The Air Force Air Weather Service's interest in this development provided support to proceed with follow-on programs.

By the summer of 1952, there was mounting evidence that primitive numerical methods were capable of attaining an average weather prediction accuracy comparable with that of forecasts prepared without the use of numerical methods. Recognizing the potential of more sophisticated numerical methods, and the equally important advantages of data processing by high-speed automatic computing machines, a number of well-placed scientists and military officers brought these new developments to the attention of the Joint Meteorological Committee under the Joint Chiefs of Staff. As a result, this committee, composed of the heads of the Air Force Air Weather Service, the U.S. Weather Bureau, and the Naval Weather Service, commissioned a special subcommittee to review the current state of development, to estimate the trend of development, and to advise the Joint Meteorological Committee on the desirability of establishing an operational numerical weather prediction unit. With excellent cooperation from the three U.S. weather services, the subcommittee completed its survey, made its recommendations, and drew up the plan for the first operational JNWP Unit in mid-1953. Briefly, the subcommittee found that numerical methods of weather prediction had already advanced far enough to justify an operational national program through the combined resources of the three national weather services. The subcommittee also recommended that a research and development group should be an integral part of the first operational JNWP Unit.

The subcommittee's recommendations were put into effect immediately upon the parent committee's approval, and the JNWP Unit was officially established on 1 July 1954. By that time, a nucleus of key people had been assembled in Washington, and, after performance tests of several production models, a high-speed electronic computer was ordered for delivery in the following spring. From its inception, the JNWP Unit has been jointly staffed, financed, and supported by the three U.S. weather services, with Air Force and Navy officers working side by side with their civilian scientific colleagues. The initial Director of the JNWP Unit was Dr. George Cressman, and AWS-employed meteorologist who transferred to the U.S. Weather Bureau about 1956.

The successful numerical models have resulted in an increased weather prediction capability. A measure of this advance is indicated in the 30-hour surface prognosis accuracy which has shown a 22% increase in skill since 1958. However, these models are still not adequate for small scale weather forecasting so vital to the severe

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weather and terminal forecasting efforts. Three major developments during the last six years are:

(1) The operational boundary layer model developed at the Air Force Global Weather Central.

(2) The local area fine mesh numerical model and the refined global numerical analysis technique developed by the Air Force liaison group collocated with the National Weather Service in Washington, D.C.

b. Flow of Technology

The joint cooperative development of numerical weather forecasting for improved meteorological support to aviation has in general terms been a concurrent inter-agency effort. The early identification of operational applications to aviation by the Air Force, resulting in DoD sponsorship, was a highly significant catalyst to the development of this weather prediction capability.

c. Civil Aviation Benefits

Weather forecasts on a global scale require:

(1) Rapid data acquisition of observed weather conditions.

(2) Rapid analysis of the data.

(3) Accurate, fast computational methods to determine the future state of the atmosphere.

Aviation meteorologists require analyzed weather charts and prognoses that provide worldwide weather patterns at several atmospheric levels within (3-6) hours of actual international observations. The use of numerical weather prediction techniques has provided the increased speed necessary for aviation forecasts. The numerical products provide the aviation meteorologist timely data necessary for accurate flight planning, hazardous weather identification and notification. NWP has resulted in the incorporation of meteorological forecasts at operational aviation decision-making levels to identify the need for aircraft ground delays to prevent airborne diversions resulting in:

(1) Passenger dissatisfaction.

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(2) Increased ground transportation costs.

(3) Increased fuel costs.

(4) Disrupted airline schedules.

d. Subsequent Development

The JNWP Unit no longer exists. However, the Air Force has approximately three NWP meteorologists assigned to the National Weather Service's Meteorological Center in Suitland, Maryland. These meteorologists work side by side with the National Weather Service's NWP personnel to further refine numerical analysis techniques.

e. R&D Costs

The costs, listed below, of developing this highly significant research effort were minimal compared to the benefits:

Year	Agency	Cost (Millions)
Mid-1950	DoC/DoD	29.7
1954-61	DoC/DoD	1.6
1965-68	DoD	0.6
1961-1971	DoC/DoD/DoT	2.7
	TOTAL	34.6

Salaries for research personnel and expenses involved in operating electronic computers are included in the above costs.

4. Visibility Measurements at Airports

Pilots require an exact knowledge of visibility conditions at the time of takeoff and landing, especially during adverse weather conditions. This information is now instrumentally derived and reported to the pilot as Runway Visual Range (RVR). In the United States, RVR is a derived value, based on standard calibrations, which represents the horizontal distance a pilot will see down the runway from the approach end. It is based on the sighting of either high intensity runway lights or on the visual contrast of other targets, whichever yields greater visual range.

a. Early Development

The basic work in this instrumentation was done by C. A. Douglas and L. L. Young in 1945 under a developmental effort

sponsored by the Civil Aeronautics Administration (CAA). The transmissometer, developed as a result of Mr. Douglas' efforts, has since become recognized worldwide and is the basic instrument used at over 350 locations in the United States. DoC, DoD, and DoT are representative governmental agencies that participated in work relating to this system.

In November 1948, the Landing Aids Experimental Station, Arcata, California, proposed to the Air Force that measurement from two transmissometers and a ceilometer, located at the approach and runway area of the airfield, be used to determine the official ceiling and visibility conditions.

The formal evolution of the current RVR concept in the U. S. probably began with a Memorandum of Agreement between the Weather Bureau and the Air Navigation Development Board dated 14 September 1951. Under this Agreement, research efforts were conducted by the Weather Bureau. The intent of the effort was to increase airport utilization by improving and augmenting terminal weather observing techniques. The technical effort included validation of the transmissometer calibrations, use of television observations, ceilometer experiments, and investigations directed toward improving runway weather observations. Flight tests were conducted to evaluate operationally the end-of-runway ceilometer-transmissometer system in terms of pilot application.

A series of studies were conducted at the National Aviation Facilities Experimental Center (NAFEC) in the field of approach visibility measurements. Flight tests were conducted from August 1959 to August 1961 to refine the approach light-contact height techniques developed earlier. Data acquisition was confined to those weather conditions with cloud heights of 800 feet or less and/or visibilities of 1 1/2 miles or less.

b. Flow of Technology

The technology of making it safer for the pilot to sight the runway and to land has been adopted by airfields of all governmental and private organizations.

c. Civil Aviation Benefits

Visibility measurements are critical to a pilot attempting landings and takeoffs. RVR technology has contributed significantly in preserving the safety record of aircraft operations involving passengers and crews.

d. Subsequent Development

Subsequent work sponsored by the FAA and the National Weather Service has been devoted to validate the RVR concept and to establish new techniques and procedures for determining and reporting RVR values under lower conditions (down to 100 feet) of visibility. Slant range visibility along the aircraft approach to runways and taxiway visual range are also being considered.

e. R&D Costs

It is estimated that the cost of this development totals several million dollars.

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SECTION III

CURRENT AND PLANNED R&D EFFORTS

All agencies contributing to this appendix have identified several important meteorological follow-on programs that will have direct benefit to the aerospace industry, especially with regard to the operational aspect of military and civilian aircraft. Some of these programs will become realities in the mid and late-1970's while others will require extended R&D efforts.

In the 1970's, the following advances appear likely:

- An increase in the accuracy of weather prediction for terminal weather conditions by an increased use of electronic computers and improved atmospheric modeling.
- A better understanding of the technique to negate the effects of wake turbulence and wingtip vortices.
- More precise ground-based instrumentation to observe/measure weather parameters rapidly and an improved aerial weather reconnaissance capability.
- Improved weather dissemination equipment.
- The ability to modify adverse weather conditions, such as warm fog and low clouds.
- A better understanding of the interaction of atmospheric pollution and aircraft operations and methods to reduce or eliminate this type of pollution.
- Remote weather briefings to aircrews by automated means.

By the end of the 1970's and beyond, the following advances appear assured:

- The ability to observe, predict, and avoid clear air turbulence.
- Continuous, real-time global weather observations by weather satellites.
- Modification of the intensity of hurricanes and typhoons.

- Receipt of near real-time surface and upper-level weather observations and forecasts by weather display equipment installed in the aircraft.

- Fully automated systems for the measurement and reporting of aviation weather parameters, i.e., visibility, ceiling, runway visual range, slant visual range, and taxiway visual range.

A. Government

1. Department of Commerce

The National Weather Service of DoC has identified the following R&D efforts that have probable application to civil aviation:

a. Project Stormfury - Project Stormfury is a joint Department of Commerce (National Oceanic and Atmospheric Administration) and Department of Defense (U. S. Navy) program of scientific experiments designed to explore the structure and dynamics of hurricanes and tropical storms. The Project's objectives are to achieve a better understanding, improve prediction, and examine the possibility of modifying some aspects of these storms. Hurricane damage is caused by wind, rain, and flood, but principally by the wind-driven storm surge which sends the sea onto the land. If the wind speed, and hence the wind force, of hurricanes can be lessened (see Figures 1 and 2) as they approach land, both death and damages may be reduced materially.

Since the beginning of this century, the hurricane death toll has declined markedly as observation, prediction, and preparedness have improved. In the decade 1900 through 1909, more than 8000 people were killed by hurricanes in the United States. Since 1940, hurricane-caused deaths exceeded 500 in only one five-year period -- 1955 through 1959. However, the decrease in loss of life is in contrast to the sharp increase in property damage during the same period (see Figure 3). Adjusting damage totals to the 1957-59 base of the Commerce Department's composite construction cost index, hurricanes caused less than $400 million in damage during the five-year period 1925-29, while deaths exceeded 2000. For the five-year period 1960-64, hurricane damages were nearly $1.2 billion, while the figure for 1965-69 rose to more than $2.4 billion. One hurricane of 1970, Celia, struck the Texas coast on August 3, causing 11 deaths and an estimated $454 million damage -- the fifth highest hurricane-damage figure in U. S. history. The dollar cost can be expected to continue climbing as greater numbers of expensive buildings are constructed in vulnerable coastal areas.

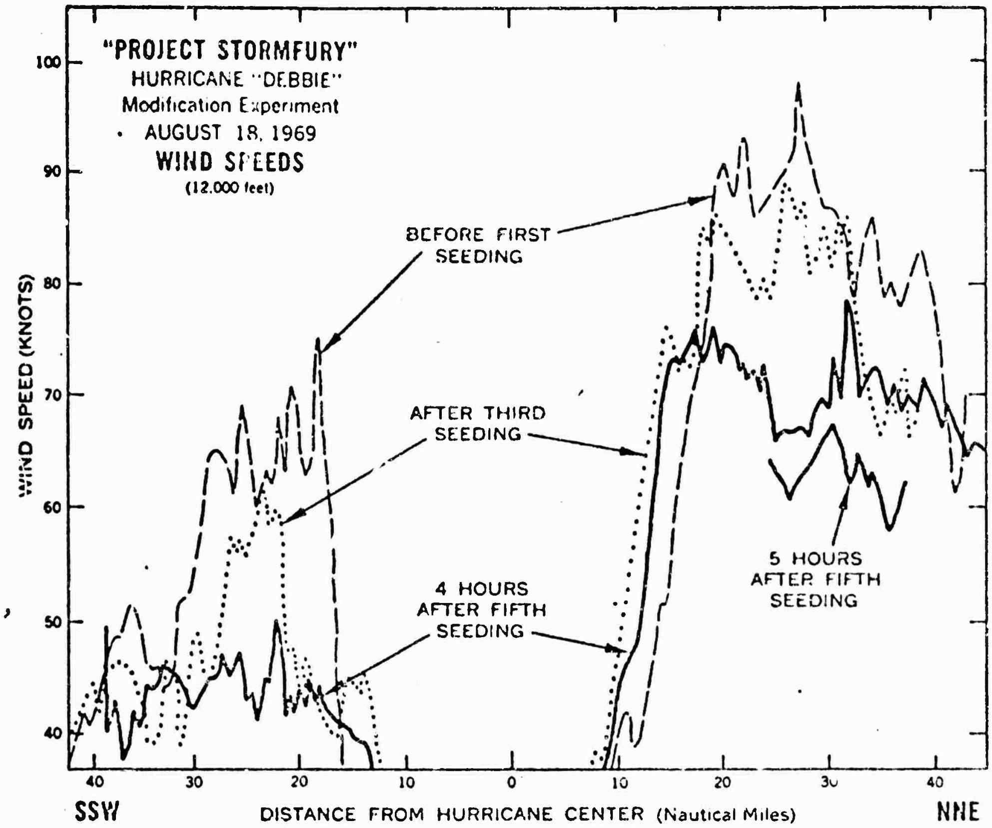

Figure 1

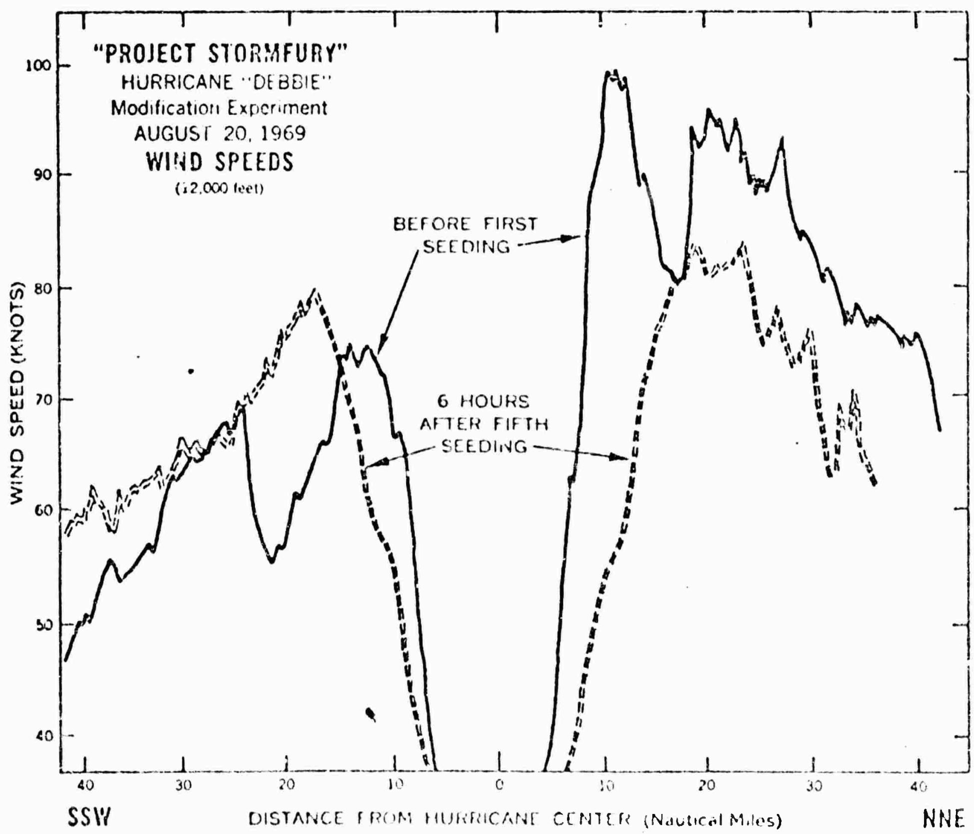

Figure 2

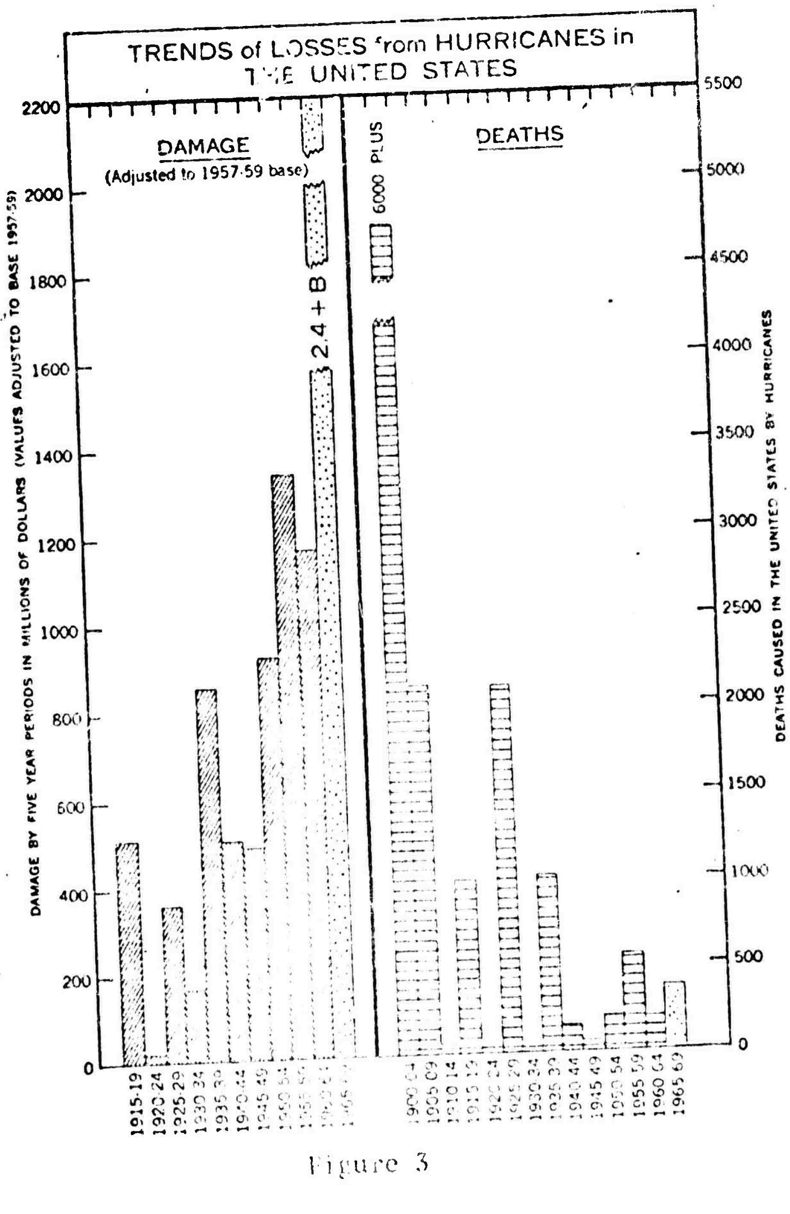
TRENDS of LOSSES from HURRICANES in THE UNITED STATES
DAMAGE
(Adjusted to 1957-59 base)
DEATHS
2.4 + B
6000 PLUS
DAMAGE BY FIVE YEAR PERIODS IN MILLIONS OF DOLLARS (VALUES ADJUSTED TO BASE 1957-59)
DEATHS CAUSED IN THE UNITED STATES BY HURRICANES
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1915-19
1920-24
1925-29
1930-34
1935-39
1955-59
1960-64
1965-69

Figure 3

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Stormfury scientists estimate that if Federal hurricane modification research continues at the present level for a decade and, in that time, if one severe hurricane such as Camille can be weakened so that damage is reduced by as little as 10 percent, the investment will have returned tenfold.

Assisting the Stormfury effort is the U.S. Air Force's 53rd Weather Reconnaissance Squadron, based at Ramey AFB, Puerto Rico. One of the Squadron's missions is to provide the DoC's National Weather Service with round-the-clock hurricane warning information. This Air Force Air Weather Service Squadron, referred to as the "Hurricane Hunters", has supported Stormfury by providing hurricane reconnaissance data as far as 2,000 miles from Puerto Rico. In 1971, the Squadron's WC-130 aircraft participated in Stormfury "seeding" activities. Air Force Air Weather Service activities in Stormfury are expected to increase when the Project is moved to the Western North Pacific in 1972 or 1973.

Benefits to aviation which may evolve from Project Stormfury include:

(1) The reduction in damaging wind speeds through effective seeding methods will reduce the magnitude of aircraft evacuations from affected geographical areas.

(2) The reduction of damage to aircraft and aircraft auxillary equipment and facilities.

(3) Improved aviation operations, i.e., operations could continue for later periods, resume at earlier times, and reduc the diversion of aircraft enroute.

b. <u>Weather Prediction</u> - Improved forecasts of terminal area weather to include the prediction of cloud bases, visibility, and wind are included in the National Weather Service's plans. Numerical and statistical methods will be employed to improve such forecasts. Also, existing electronic computer models will be adapted to derive trajectory forecasts and develop automated techniques for predicting severe storms, e.g., tornadoes, and the storm's intensity.

c. <u>Weather Dissemination Equipment</u> - To satisfy the data requirements of users at various locations, the National Weather Service is determining the best methods for mass dissemination of weather information using electronic computer programs. Equipment to be employed include television, radio, and telephone lines. The

Departments of Defense and Transportation are also planning for mass dissemination of weather information.

d. Weather Observing Equipment - An Automatic Meteorological Observing Station (AMOS) and a remote version of AMOS, i.e., RAMOS, are being developed as self-contained, automatic observing systems. Two weather parameters of vital interest to aviation, i.e., visibility and ceiling, cannot be automated at present. However, automatic visibility observing equipment is undergoing test evaluation and ceiling equipment using infrared sensors and laser technology are under consideration.'

e. Weather Radar - A digitized radar experiment (D/RADEX) has been designed to determine the applications of digitized radar and to recommend an ensuing operational system. Four radar stations have been provided with equipment to convert radar signals to a digital format. The experiment will have application to all types of aviation because of radar's role in observing severe local storms. Specifically, the experiment will help to determine the role of computer technology in analyzing thunderstorm intensity and movement, as well as the computer's role in helping to communicate timely warnings. The Air Force has identified the probable use of digitized radars to support its operational requirements through the 1980's (see para 2a(3)).

2. Department of Defense

Air Force

The Air Force is currently planning several meteorological efforts with "spin-offs" benefiting civil aviation. These efforts include the following:

a. Mission Analysis on Air Force Weather Mission - 1985- In August 1972, the Air Force completed a study to evaluate the impact of the natural aerospace environment on Air Force and Army missions through 1985 and to determine the type and quality of weather support required for the 1972-1990 time period. Probable areas of R&D which will be addressed are:

(1) Increased meteorological satellite resolution.

(2) On-board meteorological satellite normalization, rectification, and digitization to lessen ground processing requirements.

(3) Digitized weather radar data and improved means of transmission.

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(4) On-board aircraft weather displays.

(5) Increased communications efficiency via communication satellites.

(6) Improved global weather models to include solutions to truncation errors (errors resulting from the approximation of mathematical derivatives) and stability problems.

(7) Techniques for remote sensing of weather parameters in denied areas by utilizing microwave and satellite systems.

b. Clear Air Turbulence - Experimental investigations are continuing to study the nature of turbulence in the clear atmosphere at jet flight altitudes. The purposes of these studies are to develop improved techniques for forecasting CAT-prone areas and to establish a meteorological basis for the development of airborne devices to detect CAT ahead of the aircraft. Increasing evidence indicates that CAT is the result of the breakdown of wave-like motions in layers where there are strong vertical wind shears. While significant progress has been made in identifying turbulence with specific small scale meteorological features, further progress requires increased knowledge regarding:

(1) The time and space variations of these features

(2) The relationships of these features with those on the larger scale, i.e., the usual operational scale of information and analysis.

To that end a concentrated field observation program of an exploratory nature was carried out with measurements obtained from radar, aircraft, and special meteorological observations. A follow-on program was conducted by the Air Force Cambridge Research Laboratories during a 6-week period in early-1972 over western Texas.

Turbulence created in the clear atmosphere by strong vertical wind shears can seriously affect aircraft travel. CAT is especially troublesome because it is encountered unexpectedly without visual evidence to warn the pilot. Encounters with CAT become more numerous and costly as the frequency of jet transport operation increases. CAT can cause not only passenger discomfort and occasional serious injury or death, but also structural damage. This technological advance has important implications for other agencies such as the Departments of Commerce and Transportation. These agencies are conducting related investigations.

c. Fog Dispersal

(1) Supercooled Fog - Supercooled fog (i.e., fog composed of water droplets at subfreezing temperatures) restricts aircraft operations at military and civilian air terminals during winter months. While it has been known for years that certain seeding agents could be used to dissipate such fogs, it is only within the last few years that theory has been translated into routine operational results.

There are two accepted methods to dispense the seeding agents into supercooled fog, airborne and ground-based. In the United States, the United Air Lines employed the first operational supercooled fog dissipation system during the 1963-64 time period; the system dispersed crushed dry ice from light aircraft. This airborne system has proven successful and today approximately 20 to 25 other airlines and airport managers now share in the cost with the United Air Lines for this type of seeding. In 1967, the Air Force adopted this technique. The Air Force uses a WC-130 aircraft on an operational basis to dispense crushed dry ice at ten bases in the United States and Europe.

The second dispersal method was developed by the Air Force and incorporates ground-based liquid propane dispensers presited to compensate for the local wind conditions occurring most frequently with supercooled fog. The dramatic success of the first such Air Force system at Fairchild AFB, Washington, led to the recent installation of two more ground systems at bases in Europe and Alaska. Based upon the past three years of technique refinement by the Air Force, the engineering development of standardized, remote-operating, propane-dispensing equipment has been directed. It is estimated that approximately one million R&D dollars will be required to develop this dispensing system.

Of the two supercooled fog dissipation techniques being used operationally, the ground-based approach, in particular, offers high potential value for use in support of civil aviation. Upon completion of the equipment engineering program described above, the Air Force will have accomplished all necessary technique and hardware development action for routine use of ground systems at fixed air terminals.

(2) Warm Fog - Warm fog (i.e., fog composed of water droplets at temperatures greater than freezing) has successfully resisted most attempts to dissipate it on an operational basis. It has been realized for many years that both heat and

hygroscopic (water absorbing) seeding were two techniques theoretically possible. In recent years the use of helicopter downwash has been investigated as a third possible technique. Currently, it is felt that heating methods are more feasible for operational systems. No proven operational capability currently exists in the United States.

On the other hand, French heating experiments using jet engines have shown the capability to provide the necessary clearing in the approach and landing areas. Following the French lead, AWS conducted a test in January 1968 using four C-141 aircraft spaced 750 feet apart along the runway at Travis AFB, California. In each of three five-minute tests the visibility was raised from less than 1000 feet to greater than 4000 feet. During 1972 and beyond, the Air Force Cambridge Research Laboratories will be investigating the use of heated plumes to produce similar results. The Air Force will probably pursue the development of a prototype system for warm fog dissipation. An operational capability is planned by 1977.

The application of a warm fog dissipation capability to civil aviation is obvious. Warm fog comprises 95% of that fog in the United States which hampers airline operations and causes an economic loss to the airlines of over 75 million dollars annually. At this time there are no known plans for the development of a heat-based warm fog dissipation system for use at civilian fields. As a result, the development work by the Air Force will be viewed with a great deal of interest by all aviation agencies in the United States. The dissipation of warm fog by seeding agents is also under investigation by the commercial airlines and governmental agencies (see paragraph "b" under Navy and paragraph "d" under the Department of Transportation). However, disagreement exists regarding hygroscopic and non-hygroscopic seeding agents. This disagreement, hopefully, will be resolved by currently planned airline and governmental R&D efforts.

d. Digital Graphics - In 1958 the Air Force stated a requirement for a modernized graphics capability as part of the communications subsystems to disseminate weather data. In 1959 the Air Force identified the specifications for a graphics system to operate in a digital mode, have a speed ratio of 8:1 over 120 scans per minute analog facsimile, and give a good black-on-white copy with resolution of 100 lines per inch. Basic to the equipment need was the requirement to move existing weather charts at a higher rate in order to increase their usability at Air Force bases as well as to give an increased capability for more traffic. The system would replace all Air Force facsimile worldwide and, in the Continental

United States (CONUS), would supplant drops on the National Facsimile and other systems. Initial development was done by United Aircraft Corporation (UAC) on an Air Force contract. A follow on contract was let to Edgerton, Germeshausen, and Grier (EG&G) Corporation in June 1967 for development and delivery of 125 recorders and 20 transmitters. Currently, the equipment developed by EG&G (AN/GMT-3 transmitters and AN/GMH-5 receivers) is being tested. Production is scheduled to start in July-August 1972. Existing plans are to deploy the digital graphics equipment to overseas locations prior to implementing it in the CONUS. The European areas are scheduled first.

This system could well be the beginning of a change-over to a digital system throughout the U.S. civil facsimile systems. It could have significant value in that R&D costs will already have been borne by the Air Force. U. S. civil aviation forecast support is heavily dependent upon the civil facsimile nets for Department of Commerce's National Meteorological Center and National Weather Service's weather products.

e. Remote Preflight Briefings - The Air Force is planning to replace the present face-to-face weather briefings at base weather stations with remote briefings from a centralized facility. This is expected to result in more effective use of the specialized capabilities of the Air Force Global Weather Central (AFGWC) to maintain a high quality of pilot weather briefings and reduce overall manpower requirements. The proposed remote briefings will emulate the briefings given today by a qualified forecaster in a base weather station; however, the briefings will be given remotely from AFGWC. The facilities and resources available to this briefer will be superior to those available in the field. Briefing hardware will consist of a telephone voice link, television screens for simultaneous display of briefing aids, both to the briefer and to the pilot, and a teletype printer to provide recorded information to the pilot, including computer flight plans. Since off-the-shelf equipment will be utilized for this briefing system, no R&D funding for this program is anticipated. The cost of equipment is expected to be about $70,000 per briefing station. The Air Force plans to inaugurate centralized briefing service to 10 bases in late 1973, and expand it to an additional 27 bases during 1974. Further expansion of the system will take place as necessary, with the potential of handling all Air Force briefing stations in the CONUS. This concept of centralized pilot weather briefings has an immediate application in support of civil aviation. The experience accumulated in building and using this system will be transferrable to the civilian aviation community. It could be implemented by individual airlines, or by governmental agencies. The proposed R&D programs in this area by the DoC and the DoT will greatly benefit from these initial efforts by the Air Force.

f. The Airborne Weather Reconnaissance System (AWRS) - AWRS is intended to significantly upgrade the capability of the Air Force to conduct tropical storm and routine aerial weather reconnaissance. This improved capability will be provided through use of an integrated system comprising state-of-the-art sensors, automatic data processing, and improved data transmission facilities. Sensors will be provided to accurately measure flight level temperature, pressure, dew point, altitude, sea surface temperature, wind speed and wind direction. In addition, improved sensors will be employed to measure temperature, pressure, and dew point from the aircraft to the earth's surface. An improved navigational system will be integrated to provide for precise location of storm features and meteorological conditions. Automatic data processing and display, mission control subsystems, and improved data transmission equipment will be employed for reliable, fast and accurate relay of meteorological data for use by all weather services thus benefiting civil aviation. The acquisition of AWRS will require approximately 12 million in R&D FY 73 dollars.

g. Project Seek Storm - This project will provide the Air Force with an improved airborne weather reconnaissance radar system. The system will furnish Air Force aircraft with an improved capability to collect vital data for the prediction of tropical storm movement and strength. A prototype system will be designed and developed for integration into the Airborne Weather Reconnaissance System. The prototype system will be ground and flight tested to determine the adequacy of the design concept and to provide sufficient information to enable the Air Force to make decisions regarding follow-on procurement of production models for installation in AWS aircraft. Approximately 20 to 25 million R&D FY 73 dollars will be required to acquire this radar. Tropical storm data is also used by the National Weather Service of the Department of Commerce and utilized by the civilian community including civil aviation.

h. Weather Prediction - A key to increased economical operation of aircraft, especially commercial aircraft, is an increase in weather prediction capabilities. These capabilities, in turn, depend on more sophisticated numerical models of development tasks now underway that will contribute to the total national capability in atmospheric sciences. These constitute follow-on development to eliminate known shortcomings in current operational models. The trend is toward models which predict weather directly rather than the pressure/contour patterns of the past.

Numerical prediction depends critically on the initial observational inputs to the prediction model. The initial conditions are provided by an analysis technique. The Air Force Systems Analysis and Design Group located at the Air Force Global Weather

Central is developing an improved weather analysis technique. When operational, this technique will provide the initial condition for weather prediction models to improve forecasts for both military and civilian users.

In September 1969, a new research program was undertaken by the Air Force Cambridge Research Laboratories directed toward improved short range (0-3 hr) forecasts of local weather conditions that restrict or impair the safety of aircraft operations (i.e., low ceiling and visibility, strong surface wind, and severe local storms). Automated techniques will be used to acquire, process, and display surface weather observations from a fine-scale network of stations now being established in eastern Massachusetts. Real-time mesoscale forecasting experiments will be carried out based upon data from the 26-station experimental network, which will have a station separation varying from 1/2 to 5 miles. A prime objective of the new program is to determine the benefits to be derived from computerized radar and mesoscale weather observations. An associated objective is to examine the consequences of compromise between network density and weather forecasting accuracy.

i. Atmospheric Pollution - A technique to positively identify the source of a smoke plume is currently being developed by the Los Alamos Scientific Laboratory which is operated by the University of California for the Atomic Energy Commission (AEC). Assisting in the developmental effort is the Air Force's 58th Weather Reconnaissance Squadron based at Kirtland AFB, New Mexico. This Squadron collects samples of smoke plumes at low altitudes and documents the plumes' locations, dimensions, and diffusion by high altitude photography. The Squadron is experimenting with a wide variety of photographic film and developing techniques to determine various characteristics of the plumes. One goal of this type of R&D activity is to establish aviation's contributions to atmospheric pollution from the earth's surface to supersonic aircraft altitudes (approximately 65,000 feet). Another goal is to determine the application of smoke plume sampling and high level photography to ecological and environmental diffusion studies.

The AEC effort, with support from Air Force aircraft, relates directly with NASA's Lewis Research Center upper atmospheric pollution program (see page 55).

j. Data Acquisition - Due to an Air Force requirement to disperse strike and reconnaissance aircraft globally on a very short notice, the Air Force Global Weather Central (AFGWC) developed an automated, aviation-oriented, immediately accessible meteorological data acquisition system. By 1970, AFGWC integrated surface observations, upper-air data, aircraft reports, and weather satellite information into the system. A key accomplishment included techniques

to extract quantitative meteorological data to include cloud amount, type and height from satellite data. Not only is the AFGWC system the most complete and comprehensive data base known to exist, but it is aviation oriented. It provides observed and forecast wind data and significant weather for custom tailoring into computer flight plans, point weather warnings, or terminal forecasts. Any AWS unit with the proper communications can query the data base for specific information and receive a reply in one or two minutes. This has allowed AWS to decrease the total amount of data distributed to field units, avoid human errors, and permit more efficient use of communication systems.

The AWS aviation-oriented, immediately accessible meteorological data base was developed and made operational for the support of military operations. The technical details of this system have been published in open literature and are available to the civil aviation community. These techniques and concepts can be implemented to support civil aviation. A data base oriented to the specific purpose of providing better service to aviation would have significant benefits to civil aviation, both in terms of flight safety and economy.

Navy

a. Project Stormfury - This Project is a joint Department of Commerce and Department of Defense effort (see the DoC input on page 38).

b. Fog Dispersal - The Naval Air Systems Command's Project Foggy Cloud is developing a warm fog dissipation system designed to improve aircraft operations under adverse fog conditions. Foggy Cloud's goals are to develop promising hygroscopic agents (substances that accelerate the condensation of water vapor), spray systems, and techniques that will reduce or eliminate warm fog restrictions of ceiling and visibility. This type of modification will help to eliminate those atmospheric conditions which curtail or inhibit aviation operations, both commercial and military. The estimated cost to civil aviation operations due to fog restrictions amounts to 75 million dollars annually. By the end of FY 72, the Navy estimated that 2.3 million R&D dollars had been expended to develop this dissipation system.

c. Emergency Air-Droppable Weather Buoys - A notable example of the Navy's R&D activities is the air-droppable weather buoy. These small packages can be dropped from any height into the ocean, where they will float for several days before power failure. The surface weather information, including the height of the waves, is transmitted upon demand to the inquiring aircraft using VHF radio. The Naval Air Systems Command is within two years of

successful prototype deployment of this system and the ongoing technical achievements have been made available to the National Buoy System for use in the development of the air-droppable buoy. It is probable that many civil aircraft will carry one of these buoys as part of their overwater emergency package. In cases of aircraft ditching at sea, the easy deployment of this buoy will ensure that the pilot will know the actual wind speed, wind direction, height of the waves, and altimeter setting for his emergency landing.

Army

a. The U.S. Army is now conducting an active research program which will lead to the development of remote atmospheric sensing systems. Such systems will permit the real-time measurement of such atmospheric parameters as temperature, density, wind speed, and wind direction between the surface and 50,000 feet. Use of such systems will also provide a capability for real-time surveillance of atmospheric parameters along remote air routes.

b. The U.S. Army is now developing an Automated Meteorological System (AMS) which will provide a means to organize available meteorological observations within a given geographical area and to process, summarize, and transmit in near real-time atmospheric information required for military operations. Utilization of state-of-the-science analysis techniques and available equipment will result in a first-generation system by 1976. Such a system will be of considerable value in the detection and tracking of mesoscale weather phenomena that affect civil aviation.

3. Department of Transportation

Federal Aviation Administration

FAA's National Aviation System Plan, National Aviation System Policy Summary, and the joint DoT-NASA Civil Aviation Research and Development (CARD) Implementation Plan have identified significant efforts that directly benefit civil aviation. These efforts include the following:

a. Wake Turbulence - Accuracy in forecasting atmospheric phenomenon such as wake turbulence is expected to increase due largely to improved technological innovations in weather observing and reporting. The efforts to define the effect and impact of wake turbulence on aircraft, to detect and disseminate its presence and intensity and duration, to integrate these data with other data into the Air Traffic Control system, and to reduce wake turbulence effects through procedures and/or dissipation methods are planned under FAA's Weather Information Program.

The activities include:

(1) A flight test program at an instrumented facility to determine wake generation and propagation characteristics of given aircraft classes.

(2) The prediction of wake path and intensity as a function of weather to include temperature and winds and aircraft characteristics.

(3) Determination of separation of aircraft as a function of time after passage of the generator, the characteristics of the aircraft pair and the environmental conditions.

(4) Development of criteria and procedures in accordance with (3) above.

(5) The development and testing of sensing, detection, and dissemination systems for ground-based application.

(6) Studies of cost-effectiveness and benefits to wake sensing systems.

A test facility for providing standards and quantitative data to evaluate various techniques is planned. Results from NASA efforts to modify the aircraft to reduce wake turbulence at the generating source will be tested and evaluated as a separate activity. The development and testing of ground-based systems to dissipate the near surface wake turbulence will also be carried out. Wake turbulence funding in millions of dollars through 1981 is planned as follows:

1972	1973	1974	1975	1976	1977-81	1972-81
2	2	2	2	2	10	20

b. Data Acquisition - This effort includes sustaining engineering efforts to provide for improved availability and more cost-effective operation of the present FAA inventory of weather devices, such as transmissometers, runway visual range (RVR) systems, rotating beam ceilometers, wind equipment, altimeter setting indicator equipment, and hygrothermometers.

Also included are research and development activities to improve present methods of measuring visibility and ceiling information provided to the pilot and controller. These efforts include development

and test of devices to measure very low visibilities (less than 600 feet RVR) as well as the development and test of data acquisition devices to measure slant range visual range and other required visual range data for airport operations. Efforts to automate the measurement of ceiling are also included.

Methods of detecting and sensing the location and intensity of turbulence from airborne and ground-based platforms will be carried out under this program element. Clear Air Turbulence (CAT) and turbulence associated with severe storms will be studied, analyzed, and measured. This work includes joint programs with the NOAA, DoD, NASA, and other governmental agencies.

A measure of the intensity, location and duration of wind shear in the lower few thousand feet of airspace surrounding air terminals provides important information for the safe, efficient control of terminal air operations. Representative wind data for landing and departure operations improves the operation of the individual aircraft and can assure effective assignment of the active runways. Development activities to provide both wind shear data and representative wind information for aviation use are included.

An additional effort involves developing and testing automatic and/or semiautomatic weather stations for use in those tower facilities where FAA provides needed weather observations.

c. Data Processing and Distribution - Efforts in weather data processing are directed at providing automated forecasts (not now available) as well as improvements in forecasting accuracy. Efforts to improve the forecasting on severe weather, winds aloft, terminal weather conditions, very short terminal wind shifts which require change of an active runway, and forecasts of other significant weather data are provided in this effort.

This effort also includes plans to provide the annotations of severe weather on displays for use of controllers and other users. The effort includes consideration of interpreting the acquired information prior to its display and determination of what data should be displayed as well as developing, testing, and evaluating the final method. This work is interrelated to work efforts in the enroute and terminal tower programs. Data Processing and Distribution funding in millions of dollars through 1981 is planned as follows:

1972	1973	1974	1975	1976	1977-81	1972-81
0.5	0.5	0.5	0.5	0.5	2.5	5.0

d. Fog Dispersal - Fog dispersal activity provides for:

(1) Testing of a ground-based cold fog dispersal system at an airport in the western United States and the development of system specification for such systems.

(2) Monitoring of on-going airborne fog dispersal efforts including conducting field measurement programs to obtain quantitative data for assessment of the effectiveness of such dispersal efforts.

(3) Feasibility studies and field tests of various techniques of warm fog dispersal, including full scale testing, when required, of systems leading to development of operational specifications and installation standards.

e. Weather Observing Equipment - The essence of the National Airspace System weather support for aviation is the timely availability of reliable and operationally useful weather information to all users. While drawing upon the National Meteorological Service System (NMSS) for many requirements, the FAA has the responsibility to provide additional observations and analysis required for aviation purposes only. These include supplemental observations and data collection, and the dissemination of aviation weather data.

Weather observations must be provided at all locations where there is an FAA control tower. No airport may be utilized as an instrument flight rules (IFR) alternate airport unless weather observations and reporting facilities are available.

Therefore, FAA's goal is to enhance the speed, accuracy and timeliness of FAA weather observations while reducing the observer's workload, and to provide automatic equipment. Criteria for the establishment of weather observing equipment at flight service stations (FSS) form a part of Airway Planning Standard Three as follows:

(1) Rotating Beam Ceilometer (RBC) equipment should be established to take weather observations full time at airports served by certified scheduled air carriers.

(2) Direct-Reading Hygrothermometers will be provided to all FSS facilities responsible for weather observations.

(3) Automatic Meteorological Observing Stations (AMOS) may be established at airports which provide less than 24 hour air operations but require weather observations 24 hours a day to support the Weather Bureau aviation forecast program.

f. Automated Preflight Briefing - A requirement exists to provide an automated weather and aeronautical information storage and retrieval system to increase the speed of the pilot briefing process, improve its quality, and promote greater understanding and use by the pilot.

Present briefing methods are manual and inefficient. Briefers are required to obtain needed weather and aeronautical information from copies of teletypewriter reports which are usually displayed on clipboards (or similar devices) and wall maps. This requires frequent shuffling through masses of paper with a consequent wide margin for error through omission of pertinent data. The briefer's file of data must include information on a nationwide and international basis. It has become necessary to install additional teletypewriter equipment at many locations for the sole purpose of providing multiple copies of aeronautical weather information. At some locations, up to 16 additional man-hours daily are required to cut and distribute these multiple copies to the several briefer's data files.

Since 1967, the agency has been conducting research to determine the feasibility of automating the briefing process. Current study involves methods to provide the pilot with a computer-type flight profile containing all necessary meteorological information for his route of flight. The ultimate goal of providing a direct, automated, pilot briefing service will also yield improved manpower productivity and increased accuracy of weather and aeronautical data.

In addition to the current R&D efforts, other systems under review within the agency to improve the briefing process include the following:

(1) Closed circuit television to portray current weather data at FSS briefing positions.

(2) Computer storage and retrieval systems with video displays and hard-copy readouts to provide weather and aeronautical information at FSS briefing positions.

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(3) Videophone systems.

(4) Computer storage and retrieval systems providing teletypewriter hard-copy of weather and aeronautical information along a pilot's route of flight. The input/output devices for this system could be located at non-FSS airports to provide direct pilot access.

A tentative goal is to satisfy 90 percent of the average pilot's briefing and flight plan requirements through automated means. The remaining 10 percent would represent individual requests for complex or non-routine information.

The automation of the pilot briefing process is a vital necessity in meeting forecast demands for aviation services.

g. Enroute Weather Analysis and Prediction - The most significant parameters at the upper flight levels are wind, air temperature, and the possibility of encountering clear air turbulence. Improvements in forecasting these parameters have lagged behind aircraft utilization of the upper airspace.

There is an additional need to improve enroute weather information at the lower flight levels for those general aviation pilots who must operate under visual flight rules (VFR).

The FAA has research and development efforts under way with the National Weather Service to address the above requirements. Specific purposes of these efforts are:

(1) To develop suitable techniques for automated production of forecasts of meteorological elements for flight levels between 40,000 and 100,000 feet, and to initiate research leading to preparation of forecasts for levels above 100,000 feet.

(2) The development of techniques for preparing and presenting more detailed and accurate forecasts of enroute weather for general aviation pilots.

(3) The development of techniques for producing analyses and forecasts of areas of clear air turbulence that are detailed and accurate in delineation of space, time and intensity.

h. Aviation Hazardous Weather Techniques - Losses running into millions of dollars have resulted from aircraft accidents either caused by or related to turbulence. A requirement, therefore, exists to provide improved weather warning information regarding turbulence and its avoidance at jet altitudes and speeds.

There is no agency-approved system to satisfy the requirement. The FAA is supporting research to determine data acquisition methods for weather warning information. Methods under investigation include doppler radar, fine grain weather radar, and analysis of data derived from other governmental weather networks such as high velocity wave phenomena (gust front) that is conducive to extreme gusts at ground level. A joint long term program with the National Severe Storm Laboratory (NSSL) will investigate the application of doppler radar to discover potentially dangerous convective storms.

The goal of FAA then is to develop a warning system providing accurate and timely information regarding hazardous air turbulence.

4. National Aeronautics and Space Administration (NASA)

NASA's Research and Technology Operating Plan Summary and Research and Technology Objectives have identified the following efforts that either directly or indirectly benefit civil (and military) aviation:

a. Upper Atmospheric Pollution by High-Altitude Aircraft - NASA's Lewis Research Center plans to contract with a number of airlines for studies leading to the installation of instrumentation on commercial aircraft to monitor pollutants in the world's airlanes. Requests for studies of the installation and operation of the instrument packages will begin in 1972. Test flights would start in the spring of 1973. Airlane monitoring of pollutants on a global basis could provide engine designers, fuel researchers, and environmental specialists with new insights into the nature and scope of upper-atmospheric pollution by high-altitude aircraft. Data accumulated in the proposed flight program would provide a baseline against which long-term trends in pollutant levels could be monitored and evaluated and from which engine and fuel changes needed to meet environmental standards could be deduced. Atmospheric monitoring would be performed by automatic instrumentation over worldwide long-haul air routes such as Los Angeles-London or Los Angeles-Sydney in a program planned jointly by NASA and the National Oceanic and Atmospheric Administration (NOAA). Carrier aircraft would have to be equipped with inertial navigation systems to correlate sensor data to the airplane's position and altitude. The

airlane data would be supplemented by out-of-lanes data gathered by NASA's Convair 990 research airplane operated by the Ames Research Center. Lewis Research Center is investigating the possibility of equipping 10-15 airplanes with five to six instruments to detect and measure the concentration of gaseous and particulate pollutants in the troposphere and lower stratosphere, including:

(1) Hydrocarbons.

(2) Oxides of carbon, nitrogen, and sulfur.

(3) Ozone.

(4) Water vapor.

(5) Particulates, including carbon, sulfates, and nitrates.

b. Atmospheric Parameters - NASA plans to define the atmospheric conditions in which turbulence, temperature transients, potential pressure altimetry problems, and excessive wind shears occur. The major emphasis is the atmospheric environment of high speed, high altitude aircraft. Development and acquisition of sensors needed to measure these phenomena are also included. Results of this work will be applicable to aircraft systems design as well as flight operations routing and scheduling. Observations of these phenomena will be obtained from instrumented aircraft test flights. The associated meteorological conditions will be analyzed and studied both in-house and on contract.

In another effort, NASA plans to investigate and define atmospheric parameters for use in the design and development of operational techniques of conventional and V/STOL flight vehicles. Certain parameters, such as atmospheric turbulence and hail associated with thunderstorms, represent distinct flight hazards and are important considerations to the structural design and the stability and control characteristics of the airplane. Aerosols and other contaminants relate to the operational problems of airport slant range visibility and sonic boom research. The large concentrations of jet engine exhaust products in local airport areas are becoming of increasing concern to the atmospheric pollution problem, causing reduced slant range visibility for landing and takeoff operations and public dissatisfaction. These and other atmospheric parameters will be studied through flight measurement and ground-based experimental programs and the results correlated with theoretical calculations. The goal of this effort is to define the development and growth of contaminated areas and to define methods for the prevention, identification, and reduction of these conditions.

c. Clear Air Turbulence - In this effort, NASA plans to exploit the FPS-16 Radar/Jimsphere balloon system and Marshall Space Flight Center's Ground Wind Measurement Systems to achieve a better understanding of atmospheric turbulence for the definition of atmospheric parameters required for aircraft design and operation. This will be accomplished by establishing the relationship between high resolution wind and temperature profiles and aircraft observations of CAT and the association of these profiles with synoptic and mesoscale weather conditions which produced these profiles. The results of this research, coupled with the CAT laser doppler detection system, should better establish the relationship between cause and effect and improve current CAT predictions and detection capabilities besides aiding in the development of remote CAT sensing systems.

d. Weather Satellite Data - The application of weather satellite data to the quantitative measurement of meteorological phenomena is another NASA planned R&D effort. Specifically, satellite data is applied to determine sea surface temperature, vertical distribution of atmospheric temperature, humidity, ozone, and cloud motions (winds) from geostationary weather satellites. Applications of these derived parameters may then be made to studies of mesoscale systems, planetary scale phenomena, stratospheric circulation, the radiation heat budget, and climatic change. This advanced continuous global meteorological observing system is expected to improve both long-term and short-term weather forecasts required for civil aviation planning and daily operational aviation forecasts. Improved sensors on the NIMBUS F satellite will identify atmospheric pollution, possibly along global airlanes.

e. Airborne Meteorology Program - A necessary first step in the development of satellite instrumentation, for remote sensing of the earth and atmosphere, is to obtain information basic to the understanding of factors influencing the spectral signals to be observed from space. To conduct basic meteorological studies and to support satellite instrumentation development and data analysis, NASA plans to provide an airborne platform carrying instrumentation for meteorological measurements. Experiments will be mounted and flown aboard the Convair 990 (NASA 711) and a leased Lear Jet. Local or global experiments are possible with the Convair 990. The Lear Jet will be used primarily to fly one or two small experiments on a local scale.

f. Atmospheric Weather Modification - Several R&D efforts are planned in this area. This includes studies in stratospheric photochemical changes resulting from aircraft engine exhausts; contrail effects on climatic change; geophysical modeling of exhaust emissions; terminal weather modification due to air traffic; and atmospheric heat budget balance related to the effects of engine exhaust. The estimate of five year R&D cost for these programs is $22.4 million.

SECTION IV

SUMMARY

A. Findings and Conclusions

Various governmental agencies, e.g., DoC, DoD, and NASA have been involved in the development of vertical sounding systems since 1936. These sounding systems have served the needs of the civil aviation fleet (and the military) by providing accurate observations of temperature, pressure, humidity, and winds throughout the vertical extent of the atmosphere to approximately 100,000 feet.

For the past [illegible]0 years, DoD has been, and will continue to be, the sole agency that has provided aerial weather reconnaissance. The data gathered from the Arctic regions to 40 degrees south latitude has provided invaluable atmospheric weather observations on an international basis for weather analysis purposes, especially observations that locate and measure the intensity of hurricanes and typhoons.

The potential of weather radar observations was recognized early in the 1940's by military agencies. As a consequence, DoD led the way in the development of the first ground-based radar designed specifically for weather detection purposes. Approximately ten years elapsed before other governmental agencies introduced weather radars on an operational basis. Since their genesis, weather radars have been recognized as an indispensable weather observing tool.

The thunderstorm and tornado forecasting techniques developed by the Air Force in the late-1940's and early-1950's have contributed greatly to civil aviation. The initial studies were accepted and improved within DoC and DoD and became the basis for the development of the National Storm Warning Advisory Network. The benefits to civil aviation include the early identification and warning of hazardous flight conditions and the safe travel around these affected areas.

In 1947, the Air Force pioneered development of the first weather facsimile network with a few receiving stations at Air Force bases in the eastern United States and the transmitting point at the Joint U.S. Weather Bureau, Air Force, and Navy Analysis Center, Washington, D.C. In 1958, the U.S. Weather Bureau assumed responsibility of the network. Facsimile products are indispensable to aviation meteorologists and to aircrews.

The Navy initiated the development of unmanned environmental data buoys in the early-1950's. By 1980, a network of buoys will be in place off the east and west coasts of the U.S. observing, recording, and transmitting environmental data automatically.

Aviation is vitally dependent upon the rapid dissemination of meteorological data and forecasting products. The manual data collection and dissemination techniques used through the 1950's were inadequate and were rapidly falling behind aviation's global requirements. To remedy this inadequacy, the Air Force implemented the Automated Weather Network in 1965 to speed the flow of perishable weather data. The World Meteorological Organization and U.S. civil communication systems subsequently applied the Air Force techniques to their individual needs.

The requirement to provide military pilots with the best enroute weather forecasts and flight plans prompted DoD in 1959 to initiate automated flight plans using electronic computers. Following DoD's lead, DoC in early-1967 began providing various users with computer wind data which has enabled many commercial airlines to convert from manual, graphic methods of flight planning to computerized flight plans.

Since 1965, the Air Weather Service has actively participated with FAA and NASA in a high altitude radiation study. WB-57F's have flown over 2500 hours of high altitude missions gathering radiation data which will be used to help develop regulations establishing radiation protection standards aboard aircraft flying at high (SST) altitudes.

Weather satellites, identified as feasible by early DoD studies and advanced by NASA's R&D efforts, have provided a global capability in observing the weather. Resulting forecasting techniques developed with DoC and DoT have provided significant improvements to aviation forecasts over ocean and remote areas.

Wake turbulence research associated with jumbo jets has been primarily headed by DoT and NASA leadership with DoD providing flight testing assistance. The prime benefactor will be civil aircraft operations in and around crowded air terminals.

Essential to the aerospace industry for aircraft design specifications and safe operations of aircraft in flight has been the development of Standard Atmospheres. These atmospheres include data on temperature, pressure, and density. NACA developed the first Standard Atmosphere in the 1920's; subsequently, about 30 governmental, industrial, and academic organizations have continuously updated the initial atmospheres.

The joint atmospheric turbulence projects have provided the initial data base for scientific research leading to aircraft design criteria and empirical forecasting methods. DoD was the major source of aircrews and aircraft for research programs. DoD also provided

significant inputs into scientific reports resulting from these projects. DoC, DoT, and NASA were the major receivers of the turbulence data collected. Aviation operations, both civil and military, benefited from the results of the joint research efforts.

Numerical Weather Prediction operational programs, initiated by DoD and developed under joint DoC and DoD sponsorship, have provided a major advancement to aviation weather predictions. Flight safety benefits and more efficient aircraft operations, both civil and military, have resulted from improved predictions obtained through electronic computers.

Pilots require an exact knowledge of visibility conditions at the time of takeoff and landing. Visibility observations reported by weather observers can be subjective due to physiological differences from observer to observer. In an effort to eliminate this subjectivity, and to provide pilots with the best possible visibility measurements, governmental agencies developed the transmissometer, which measures the runway visual range (RVR). RVR has contributed to preserving the safety record of aircraft operations.

It is apparent, after a review of the developmental efforts identified in the appendix, that DoD leadership has dominated the significant advances in meteorological R&D that have benefited civil aviation, either directly or indirectly.

B. Observations

In meteorology, the government has consistently been the leader in the development of new equipment or techniques. This was true in the past, is true now, and will continue to be true in the future. However, in the United States, as indeed in all countries, weather service and the research supporting it is overwhelmingly a governmental activity. This includes research in meteorology by the academic community which is largely funded by government contracts. Consequently, any meteorological advance that benefits civil aviation probably will continue to be creditable to the Federal Government.

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APPENDIX 3

AVIONICS

JOINT DoD-NASA-DoT
"R&D CONTRIBUTIONS TO AVIATION PROGRESS"
(RADCAP) STUDY

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APPENDIX 3
AVIONICS

SECTION I
AVIONICS

INTRODUCTION

This appendix is part of the DoD, NASA, DoT Study Title "Research and Development Contributions to Aviation Progress (RADCAP)" and identifies many significant developments in aviation electronics since 1925 leading to the Avionics of today and tomorrow. This appendix addresses itself primarily to the technology development pertinent to civil aviation and sponsored by the Department of Defense or jointly by the DoD, NASA and DoT. This study does not cover technology developments in areas such as: special military mission aircraft and equipments, weapons delivery, electronic warfare, missiles, reconnaissance, ground handling, test equipment, manned and unmanned space vehicles and equipments which do not have a direct relation to civil aircraft.

During the twenties both civilian and military aviation were improving the much needed capability for communication and navigation. World War I Signal Corps Radio Sets SCR-59 and SCR-68 were the primary aircraft communication equipments. These required a wind driven generator. In the navigation area, the Bureau of Standards and the Army Signal Corps working together developed the four course low frequency-radio range to be used in this country. U.S. Bureau of Standards developed the Cross-Loop antenna and Army S.C., expanded on this by adding "A" and "N" and providing a goniometer in the antenna to adjust the "course". During the twenties radio broadcasting developed in the United States. KDKA went on the air in 1922 and WEAF, the first Quartz Crystal Frequency Control Transmitter, started broadcasting in 1924. By 1925 there were over 700 radio broadcast stations operating and hundreds of thousands of home receivers in use. These commercial developments provided a large electronic industrial and technological base in the United States for future avionics.

The major advancements during the early 30's were the tuned-radio frequency command set SCR-183, the direct frequency controlled BC-224, BC-348 Superhetrodyne Liaison Receiver, 2 to 20 MHz, the 75 MHz Marker Beacon, the Left-Zero-Right Radio Compass, Compass Locator Transmitters, and the Army Air Corps "AIA" Instrument Landing System (which was adopted by CAA as standard), the training of many pilots in Instrument Landing and the installation of a large number of radio ranges by CAA throughout the United States. Major advancements in electronics for aviation began to occur in the late 1930s at the beginning of WW II. Development of the Automatic Radio Compass SCR-269, 150 to 2000 KHz, was completed in 1937 and procured in large quantities in late 30's, installed in most military and some civil aircraft during the war. This type radio compass is still widely used in civil aircraft, small

aircraft and military cargo type. During the late 30's and early 40's the VHF/UHF Instrument Landing System SCS-51, was developed and installed at airfields all over the world and in aircraft, civil and military. This is the same system used today. Military research and developments were initiated to improve aviation electronics for military needs. These activities were devoted to not only improvement of communication and navigation but to the development of radars, magnetrons, klystrons, transistors, microwave equipments, antennas, radomes, fire control systems and bombing navigating systems.

The 50 to 60 era saw development of VAR and VOR omnia ranges, DME, TACAN, VORTAC, Inertial Navigation, Radar Altimeters, Weather and Doppler Radars, Computers, and Guidance Systems.

The 1960 - 72 era started with the announcement of the development of the integrated circuit and rapid development of an industry complex to build and apply integrated circuits. From 1962 to 1970 the industry built and sold $3 Billion of integrated circuits. Orders of magnitude reduction in size and weight and a break through in reliability and miniaturization occurred. By the latter part of the 60s, small, light weight, high reliability, integrated circuit computers were available and used in aircraft and missiles for navigation and guidance.

SECTION II of this report details chronologically, significant advances in different avionics areas from 1925. The areas covered are: (A). COMMUNICATIONS: Very High Frequencies (VHF) Ultra High frequencies (UHF), Satellite (COMSAT). (B). NAVIGATION; VORTAC, INERTIAL, DOPPLER, RADAR ALTIMETER, WEATHER RADAR, LANDING SYSTEM, GROUND CONTROL APPROACH (GCA), OMEGA, NAVIGATIONAL SATELLITE (NAVSAT). (C). IDENTIFICATION. (D). COMPUTERS; ANALOG & DIGITAL. (E). GUIDANCE SYSTEMS. (F). AIR TRAFFIC CONTROL. (G). DEVICE TECHNOLOGY; ELECTRONIC PARTS & TECHNIQUES, ANTENNAS & RADOMES.

SECTION III of this report covers current and planned avionics research and development efforts which may find application in civil aviation.

SECTION IV of this report is a summary and a discussion of future trends.

ABBREVIATIONS: The abbreviations used herein are defined at the end of this appendix.

SECTION II
AVIONICS
SIGNIFICANT ADVANCES SINCE 1925

A. COMMUNICATIONS

Significant developments in Communications have been the extension of the frequency range, for transmitters and receivers, from the low frequency range in kilohertz in to the microwave region of thousands of megahertz, to infrared and coherent light laser beams. Equipment developments have progressed from modulating simple oscillators as transmitters and regenerative receivers to manually tuned radio frequency receivers and transmitters to quartz frequency stabilized multi-channel (4000 or more) push button equipment, with capability for amplitude modulation, frequency modulation and digital modulation. Single sideband (suppressed carrier and sideband) techniques are available for increasing the number of channels.

Future trends are closer channel spacing, world coverage utilizing satellites, and greater use of digital technology to handle continually increasing communications traffic. As more and more avionics equipments are being used, in essential to mission and flight situations there is increasing emphasis on reliability, maintainability, modular construction, self test features, automated testing, and automated logistic support systems. Communications background is shown in Table 1. Communications satellite background is shown in Table 2.

TABLE 1 AVIONICS - COMMUNICATIONS BACKGROUND

1902 Marconi; Translantic Radio Transmission.

1906 DeForest; Vacuum Tube.

1911 Lt. Paul Beck; Signal Corps, U.S. Army; First radio telegraph messages transmitted from Aircraft.

1914 Lt. J.D. Mauborgne and Lt. H.A. Darque; Signal Corps, U.S. Army, First Voice Radio Message received in an Aircraft.

1917 Army Signal Corps developed SCR-59 and SCR-68 Radio Sets installed in WWI Aircraft. (These were the radio's used by Army Air Corps during the 20's)

1922 KDKA started radio broadcasts.

1922 Heising developed method of modulating radio frequency currents.

1922 Edwin H. Armstrong, invented the Superheterodyne.

1924 WEAF, first Quartz Crystal Controlled Radio Broadcast transmitter.

1922-1925 Over 700 Radio Stations installed in the United States and hundreds of thousands of receivers produced for Radio Entertainment.

1927 First survey of Aviations special radio needs by Boeing & Bell Laboratories, covered radio and acoustic noise, selection of the best frequency, communication needs, power supplies and weight reduction.

1928 Radio Frequency Allocations to aircraft and others. International Radio Telegraph Conference, Washington, D.C., 4 Oct to 25 Nov 1928.

1932 Army Sig Corps and Boonton Radio Co. (later Aircraft Radio Corp), developed The Command Radio Set SCR-183. This was a tuned radio frequency voice modulated receiver and transmitter which covered the frequency range of 200 to 400 KHz and 2000-18000 KHz by changing coil sets. Later the BC-191 transmitter was used with the receiver of the SCR-183 Set and became the Liaison Radio Set. These sets were used by the Air Corp. thru WWII - (1946). The SCR-183 Set was produced by Aircraft Radio and Western Electric (Graybar) Co. The BC-191 transmitter was produced by the General Electric Co. and Farnsworth Television Co.

1933 Major Edwin H. Armstrong, Signal Corp., invented Frequency Modulation (FM).

1936 Army Sig.Corps with RCA developed the BC-224 receiver covering 2000 to 20000 KHz. This was a high performance Receiver, first one designed to withstand aircraft environment, direct frequency calibrated with a crystal filter and local oscillator to receive either AM or CW or MCW. With BC-191 transmitter this became the Standard Liaison Set, SCR-137 used during WWII.

1940 SCR-274-N, AN/ARC-5 developed by Navy and Aircraft Radio Corp. employed 4 plug-in transmitter units, 2 to 7 MHz, and 4 plug-in receiver units tuneable over frequency range 200 KHz thru 9 MHz were used in Navy and Army Air Corps Aircraft as the HF Command Set.

1941 The AN/ART-13 Liaison Transmitter contained 10 preset remote selected channels. Developed by Collins. Later adopted by Army Air Corps replacing the BC-375 transmitter which was produced by Stewart Warner. ART-13 plus BC-348 Receiver became ARC-8 Std Liaison Set.

1941-1944 SCR-522 - The Army Sig.Corps under Contract to Bendix Radio Corp. developed and produced a VHF Command Transceiver which was produced in large numbers by Bendix, Colonial Radio, and Zenith. The design was based on a similar British design. This marked an important breakthrough in VHF technology going from high frequency to very high frequency band, and opened up the 100-156 MHz band to Communications using precise crystal controlled (4 preset) channels. Development of this set costs $8,000,000. Approx. 235,000 of these

equipments were produced at an estimated cost of $350 million.

1944 AN/ARC-3 The Army Sig.Corps under Contract to Colonial Radio Corporation (now Sylvania) developed an automatically tuned replacement for the SCR-522, 100-156 MHz, Dev Cost Est. $800000. The AN/ARC-3 incorporated important advances in peak noise rejection technology and included 8 Preset Channels. About 39,000 equipments were procured at a cost of $110 million.

1946-1950 The USAF initiated development of the first UHF Command Set in the 225-400 MHz band. The initial design AN/ARC-19(XA-1) was developed by Bendix Radio and later produced as the AN/ARC-33 in limited quantities. This radio marked an important move into the higher frequency UHF band. (1750 Channels). This was the first Command Set using Crystal saving frequency circuits at UHF and had 20 Preset Channels. A derivative design AN/ARC-34 was produced by RCA and Magnavox. Introduced combined transmitter-receiver design called transceiver.

1946 First Airborne Teletype installed in Pres. Truman's C-54 flying White House. Army ground based frequency shift teletype equipment modified radically to fit aircraft and work thru on board radio equipment by Army Sig Corp engineers Ft. Monmouth, N.J. Installation by Douglas.

1948 USAF developed an automatic antenna coupler for high frequency Radio Equipment cost $100,000, thus providing capability for remote automatic tuning of antenna.

1950's Collins 618-S Improved Commercial AM-HF Radio Set with remote antenna tuning. Installed in cargo aircraft.

1953 AN/ARC-44 developed by USAF were first FM systems in USAF A/C.

1954 The AN/ARC-21 was the first fully automatically tuned remote controlled radio, 2-24 MHz, 20 preset channels, developed by USAF-RCA. First HF Radio Set using crystal saver circuits and remote automatic antenna tuning.

1957 AN/ARC-58 First fully militarized airborne SSB equipment. 2-30 MHz. USAF-Collins Radio Co.

1958 The AN/ARC-21, modified for Single Side Band (SSB) operation became the AN/ARC-65. About 3000 sets were procured at a total cost of 36 million.

1959 A radio developed by Collins (type 618-T) for airlines was adopted by the USAF, USA and USN. SSB, 2 to 30 MHz, smaller and lighter than AN/ARC-65. For the B-58, HF, SSB Comm, a new design was developed by Hughes as the AN/ARC-87. It was replaced by the AN/ARC-110, a version of the 618T.

1963 AN/ARC-90. AM Freq Transceiver and Data Link - 3500 channels, Channel spacing 50 KHz, 30 watts, Made by Magnavox. First use of spread spectrum techniques.

1964 AN/ARC-54. FM Transceiver - 30 to 70 MHz, 800 channels, 10 watts. Made by Collins Radio for US Army.

1964 For the F-111 aircraft the HF, 2 to 36 MHz, AN/ARC-112 was developed by Collins. It was replaced in later models by a totally new design representing a substantial weight and size reduction.

1965 USAF - AVCO developed the AN/ARC-123 to replace AN/ARC-112. About 425 were procured at a total cost of $7.25M. This is first HF Radio with 280,000 channels, separation 100 Hz.

1965 AN/ARC-109. AM Transceiver - 3500 channels, HF, 30 watts, channel spacing 50 KHz, transistorized. Made by Collins Radio. First communication application of integrated circuits. Development cost $3.8M. AF - 250,000, Collins $3 million. Now 1600 in AF F-111, T-37, F-106, DC-9 Hospital, F-15.

1967 US Army initiates SLAE (Standard Lightweight-Airborne Equipment) program. Control panel configuration. AN/ARC-114 VHF FM; AN/ARC-115 - VHF AM; AN/ARC-116 - UHF AM.

1967 A radio similar to the ARC-123 but of 1 KW rating was developed for the C-5 aircraft. It carries a commercial nomenclature of AT-440.

1967 USAF development of high reliability UHF radio transceiver AN/ARC-144(RCA) and AN/ARC-145(ECI). These transceivers made greater use of microcircuits and solid state construction. Capable of AM, FM & FSK modulation, Reliability 1000 hrs MTBF, Cost $3.2 million.

1970 AN/ARC-150 First USAF-Magnavox developed panel mounted UHF transceiver.

TABLE 2 AVIONICS - COMMUNICATION SATELLITE BACKGROUND

1946 Army Signal Corps. sent and received a radar signal from the moon.

1945-1950 Tests involving airborne radio relays conducted by USAF.

1958 Demonstration of Time Division Data Link from Experimental SAGE Section at L.G. Hanscom Field through a B-25 relay to an F-86 receiver near WPAFB.

1958 USAF launched first active communication satellite SCORE. Broadcast President Eisenhower's Christmas message from a tape recorder. Batteries lasted 12 days.

1960 Lofting of 300 MHz transmitter - Telemetry for missile experiments - Range instrumentation transition from VHF to UHF.

1960-1961 ECHO and Grid Sphere demonstration of point-to-point communication.

1962 TELSTAR AT&T - First demonstration of active TV relay.

1965 USAF program to test the feasibility of using a satellite relay to increase range and reliability of UHF Communications between aircraft and ground terminals.

1966 Experimental airborne terminals via SYNCOM I & II (Hughes).

1966 Installation of communication satellite terminals in aircraft, ship, and ground stations by USAF, Navy, Army.

1966 Army ADVENT, AF studies on STEER, CSAR, and LOTUS led to P-band prototypes using MIT/Lincoln Laboratory Experimental Satellite in conjunction with military aircraft and ground stations over near-hemispheric zones.

1967 Test and demonstration of teletype UHF Communications between various terminals via LES-5.

1968 Initiation of TACSATCOM procurement cycle and test program using USAF-Lincoln Lab. LES-6.

1969 USAF-Hughes Aircraft TACSAT I launched. Contained UHF and SHF transponder. High antenna gain and RF power allowed users to access the satellite with analog FM voice channels and 2400 BPS Digital voice circuits. Terminal systems airborne and ground were developed by Collins Radio.

1969 UHF airborne transceivers AN/ARC-151 (ECI) and AN/ARC-152 (RCA), compatible with satellite operation were developed. Provided frequency offsets for the up and down links at 100 watts FM.

1969 The AN/ARA-64 Airborne Satellite Communications terminals were developed and fabricated. (ECI-USAF).

1970 Command Post installation using LES-6 and TACSAT.

1970 Twenty-seven AN/ARA-64 were procured and installed in the World-Wide Airborne Command Post Aircraft. This initial USAF operated satellite communications system uses UHF at 75 BPD (100 WPM teletype) and requires the use of both LES-6 and TACSAT-I.

1971 Commercial adaptation of UHF-SHF system. Procured by NATO countries.

B. NAVIGATION - VORTAC

Table 3 is chronological background on significant events leading to the development of VORTAC.

VORTAC - Ground, area navigation:

The ground non-directional radio locators (200 to 1700 KHz) for use with airborne radio compasses will continue for many years, because of their low-cost, simplicity and wide selection of available broadcast stations and as a back up to other methods of navigation. The application of integrated circuits will further reduce cost, size and weight of these equipments.

The VOR omnidirection range (VOR) 108 to 118 MHz will continue for many years. The combination of VOR and distance measuring equipment (DME) and Tactical Air Navigation System (TACAN) VORTAC will continue with continuing modification to improve accuracy of VOR Stations and higher capacity from DME.

TABLE 3 AVIONICS - NAVIGATION, VORTAC

1921 Bu Standards consisting of two large loop antennas at right angles to each other installed by Army Sig.Corps at McCook (now Wright Field) Dayton, Ohio. Army Sig.Corps keyed the loops "A" and "N" and added a goniometer to the antenna so that the courses could be adjusted without moving the antennas.

1927 Radio Range received favorable notice in Oakland to Honolulu air race. Army Sig.Corps installation of "A" - "N" range at Oakland and at Honolulu received at each station, 2400 miles.

1928 First, low frequency, 220-415 KHz four course range installed at Chicago. Provided Aural A-N signals to the aircraft pilot thereby defining the course he could fly toward or away from the range station.

1929 Four course radio range adopted as standard for U.S. 9 stations in operation.

1933 Four course radio ranges installed on major US airways. False on-course indications usually within 5 degrees of true course were experienced over mountainous areas and at night. A vertical antenna system was developed and adopted for the ground station and this satisfactorily disposed of night errors associated with the old loop antennas. There were 323 stations in use in 1941, 378 in 1949 and 332 in 1957 at which time they were gradually decommissioned. A large number are still in use at foreign airfields. This system was in use for 28 years.

1937 Bureau of Air Commerce began the development of a VHF (very high frequency) omnia directional range and next the visual aural range (VAR).

1944 The first VAR's installed by CAA. VOR's became available for testing.

1946 First airborne distance measuring equipments (DME) developed by Military. First ground station developed by FAA (formerly CAA).

1946 CAA installed VOR along Chicago-New York route parallelling older ranges.

1948 CAA program began to convert to VHF omni-directional radio range (VOR) which provided greater navigational accuracy.

1948 Initial TACAN developed by Navy-ITT. This is a Polar Coordinate System similar to VOR but combining DME operating at UHF to reduce size.

1950 Large scale CAA installation of VORs began.

1953-1954 TACAN became available. The airborne circuits based on UHF technology were sensitive and reliability was poor.

1956 The military began operation of the ultra high frequency TACAN system. The ground station (962-1024 and 1151 to 1213 MHz) transmits the azimuth signal and provides distance information in response to an interrogation signal.

1957 VORTAC, a combination of TACAN-VOR/DME was developed and implemented by FAA to provide a common civil/military navigation system. Civil aircraft use a DME receiver-transmitter which interrogates the ground station and derives range information from the DME function of the TACAN transponder. Azimuth information is obtained from the VOR (very-high-frequency omni-directional range) system. Military air-

craft derive both range and azimuth information from the TACAN ground station.

1958 CAA developed Doppler VOR which is less susceptible to errors due to site location. Order to integrate into NAS issued Aug 1964.

1967 Installation by FAA of 950 VORTAC Stations completed.

1971 VORTAC system improvements developed and modifications made to suppress harmonics of the Reference Carrier in order to reduce adjacent channel interference.

1972 Tacan with Y Mode, which provides 126 additional channels, installed in USAF's F-106, C-5 and F-15.

B. NAVIGATION - INERTIAL NAVIGATION SYSTEMS

The Inertial Navigation System, by measuring the aircraft's acceleration and processing the information in a computer, provides instantaneous and continuous indication of the aircraft's position, ground speed, azimuth and vertical. It is completely self contained, non-radiating and non-jammable system. Navigation information is obtainable at all latitudes, in all weather and without reference to a ground station. The position and velocity information degrades with time and the equipment is expensive.

The original development at MIT took 5 years at an estimated cost of $10 million per year and the equipment weighed 1500 lbs with 1 nautical mile per hour accuracy. Continuous product improvements over the past 22 years have made commercial equipment available for large commercial or executive type aircraft, weighing 70 lbs and at a cost of $100K. Cost reduction to $50K per installation is possible. Low cost, moderate accurate equipments, with simple computers seems inevitable and would find wide use in small as well as large aircraft.

Table 4 is a chronological background of significant events leading to the development of Inertial Navigation Systems.

TABLE 4 AVIONICS - NAVIGATION INERTIAL

1948-1953 Development and flight test of the SPIRE Inertial Navigation System developed by USAF and the Massachusetts Institute of Technology. Demonstrated the technical feasibility of accurately navigating long distances without reference to land marks or other external references. Weight: 1500 lbs. Accuracy: 1.0 NM/HR (CEP). Estimated cost: 10 million dollars/year.

1950-1954 N-5A/G INS, developed by USAF-USN-Autonetics (North American Rockwell), was the first inertial system suitable for operational use in USAF Hound Dog and Navy A3J.

1955-1959 LN-1, LN-2, LN-3, USAF - Litton development of a small, light-weight analog INS was the first medium accuracy, low-cost inertial system. Recurring cost in large quantities (approximately 4,000) is $70,000. Weight: 75 lbs. Accuracy: 3 NM/HR (CEP). For Navy E-1, A-6, P-3 aircraft and Air Force F-4 aircraft. Estimated cost: 2 million dollars to demonstrate feasibility.

1962-1965 USAF - AC Electronics (Delco Electronics) Carousel I, INS. Development system only - none were produced. First use of platform rotation technique to obtain good quality inertial navigation using low quality gyroscopes. It led the way to the development of the present A-C Electronics Carousel IV. Weight: 130 lbs. Accuracy: 0.6 NM/HR (CEP), for Tactical aircraft. Estimated cost: USAF-1.8 million dollars; AC Electronics, 2.0 million dollars.

1965-1966 Sperry SGN-10 developed for Pan American Airways. Dev. cost est. $58 million. Discontinued because did not meet accuracy requirements. First use of integrated circuits in inertial equipment.

1965-1967 Kearfott in-house development of KT-70 series of inertial platforms competitive with that in the LN-1 above. Performance and maintainability are somewhat better. Weight: 35 lbs. Accuracy: 1.0 NM/HR (CEP), for Navy F-8C and A-7 aircraft, Air Force F-105, A-7D aircraft and the SRAM. In-house development cost about $5 million.

1966 US Army-Litton developed AN/ASN-86.

1966-1968 Litton in-house developed integrated circuit LTN-51 commercial system based upon LN-15 developed for Military application LN-15 by Army, Navy and Air Force. Weight: 70 lbs. Accuracy: 1.0 NM/HR (CEP), for large commercial and executive, AF Gunships, Presidential fleet. Approx. 600 total qty.

1966-1968 AC Electronics (Delco Electronics) developed integrated circuit Carousel IV INS. Weight: 73 lbs. Accuracy: 1.0 NM/HR (CEP), for large commercial and executive aircraft, and AF Command and Control aircraft. Estimated cost: 30 million dollars.

1966-1968 Kearfott-Collins developed INS - 61B. Weight: 75 lbs. Accuracy: 1.0 NM/HR (CEP), for large commercial and executive aircraft.

The latter three commercial systems above - all selling for about 100,000 dollars - have exceptionally good reliability. In-flight reliability (that is, reliability after take-off with two working systems) is approximately 2000 hours.

1967-1970 Army S.C.-USAF-Teledyne development of Flight Reference Stability System (FRSS) light weight, small inertial platform 1.5 NM/HR.

B. NAVIGATION - DOPPLER NAVIGATION RADARS

The Doppler Navigation System is a self-contained, dead reckoning navigation system. It uses a radar to measure the aircraft's ground velocity, and by means of a directional sensor and computer, the system can provide: distance travelled from the point of departure, ground speed, drift angle and vertical velocity.

Doppler navigators require no ground stations, are very accurate, have all weather capability, can be used over oceans and undeveloped areas. Doppler navigators have been in use in aircraft since 1949 and are installed in many different types of Army, Navy and Air Force Aircraft. Doppler navigators by themselves and integrated with other methods of navigation will find more and more utilization by civil aircraft.

Product improvements in using solid state techniques, microcircuits show promise of obtaining equipment of 10 lbs and costs less than $10K. These systems will find high use in all kinds of aircraft including Helicopters as back up to other methods of navigation.

Table 5 is a chronological background of significant events leading to the development of Doppler Navigation Radars.

TABLE 5 AVIONICS - DOPPLER NAVIGATION RADARS

1842 Doppler effect discovered by Christian Doppler.

1945 Principle of doppler navigation suggested by the MIT Radiation Laboratory.

1945 Naval Research Laboratory conducted investigations on C.W. techniques. Extensive effort exerted in-house by Army Sig. Corps. and General Precision Laboratory on the utilization of multiple beam returns for coherence.

1949 First airborne doppler navigation radar, AN/APN-81 (XA-1) fabricated by General Precision Laboratory, delivered to the Air Force. Extensive flight testing conducted at WPAFB.

1955 Bendix fabricated a doppler (DRA-12) for use in commercial airlines. This radar was used on a very limited basis on several Air Force programs.

1955-1960 Doppler navigation radars first installed in operational aircraft. Various versions of the production AN/APN-81 doppler radar were utilized in various aircraft. The AN/APN-82 (APN-81 with AN/ASN6 Analog Computer) was used in F101. AN/APN-89 (APN-81 modified outputs) for B-52 E/F/G/H Bomb-Nav. Systems. AN/APN-108 (APN-81 modified outputs) for B-52 C/D Bomb-Nav. Systems.

1960-Present Doppler development continued with emphasis on reduced weight and increased performance, such as more accuracy and reliability. Following are some of the more significant equipment developments and aircraft application:

AN/APN-102 (General Precision Labs) - pulsed doppler, weight 90 pounds - used in RF-101.
AN/APN-113 (Raytheon) - First operational C-W doppler - used in B-58 - weight 150 pounds.
AN/APN-131 (Laboratory for Electronics) - C-W doppler used in the F-105. This was an improved version of the APN-105 also used in the F-105.
AN/APN-147 (Canadian Marconi Corp) - FM/CW doppler used in the C-130 and C-141.
AN/APN-153 (General Precision Labs) - Pulsed doppler used in the Navy's A-6 and E-2 aircraft. This was the most economical doppler radar produced.
AN/APN-172 (Canadian Marconi Corp) - FM/CW doppler radar developed for the Navy IHAS.

AN/APN-175 (Canadian Marconi Corp)-FM/CW doppler radar used in the CH-3 helicopter.
AN/APN-185 (General Precision Labs)-High accuracy pulsed doppler developed for the FB-111 and A-7D.
AN/APN-189 (Canadian Marconi Corp)-High accuracy FM/CW doppler radar used in the F-111D.
AN/APN-193 (Ryan)-CW doppler used in drone application.
AN/APN-200 (Ryan)-CW doppler used in the Navy S-3A, 41 pounds, fixed antenna, integral radome, maximum utilization of solid state devices.

B. NAVIGATION - RADAR ALTIMETERS

Early developments by the Navy of radar altimeters started in 1937 which culminated in the SCR-718 military standard Hi altitude radar altimeter. These radars operated in the 410 to 440 MHz area and recent rulings by FCC require that all altimeter operation in this area cease by 1973. In about 1968 the low level, short pulse low altitude radar was perfected and is considered the most accurate and least compromised method of obtaining altitude from 0 to 10,000 feet. There are a number of types used in many different aircraft. The Navy-Hoffman has developed the APN-201 completely solid state altimeter. The availability of solid state devices allow reductions in size and weight. Radar altimeters of the future will be about 100 cubic inches and weigh about 5 pounds. Present types used in civil aviation are of the FM/CW counter type covering -20 to 2500 feet. Table 6 is a chronological background of significant events in the development of Radar Altimeters.

TABLE 6 AVIONICS - RADAR ALTIMETER, BACKGROUND

1937-1945 Original design effort by RCA and Raytheon on the Navy AYD-3 and ARN-1 provided the "know-how" to produce the APN-1, the first military standard low level electronic altimeter. This effort combined with the RCA design and development of the SCR-518 and SCR-618, produced the SCR-718 series for the military standard high altitude altimeter. Although the APN-1 has long been obsolete, the SCR-718 continues in use in numerous aircraft such as KC-135, early C-130, KC-97, C-46, C-47, C-54, C-118, etc. Both equipments operate in the 400 MHz region (410-440 MHz). Recent rulings by FCC require that all altimeter operation cease, in 400 MHz band, by January 1973.

1945-1960 WWII operational experience revealed the desirability of extended ranges, dial and pointer type indicators and altitude control of flight control systems. Raytheon produced the APN-22 and APN-117 to provide FM/CW altimeters with these parameters. RCA used a basic SCR-718C to provide dial and pointer indication and altitude warning systems for the high altitude altimeters. These were the development and service test models - APN-42 (XA-1, 2 and 3). The APN-57, designed by RCA, was the first altimeter to provide altitude in electronic/electrical format for use with mapping/reconnaissance systems.

1962-1966 FAA developed low-range light weight radio altimeter and demonstrated suitability of this system for use in automatic landing systems.

1960-1972 Early in 1960 an attempt was made to use the APN-22 in a B-52 low level application. However, the AP .-22 proved to be highly susceptible to high level acoustical noise. Thus, the APN-150(V), a Bessel function type FM/CW altimeter, came into being. Shortly thereafter, the first short pulse low altitude altimeter design was started (APN-141). In this period, the CFE total system concept was implemented with the APN-159 being developed for the F-4/RF-4 aircraft. About the middle of this period the low level short pulse altimeter was perfected and presently considered the most accurate and least compromised method of obtaining altitude information from 0 to 10,000 feet. Among this type are the APN-141, APN-159, APN-167, APN-171, APN-184, APN-192, APN-194, APN-198, APN-203, ZPN-1 and DPN-83. These are used in such weapons systems as the A-7D, RF-4, F-111, HH-53, B-57G and A-7E. The APN-201 is undergoing tests and is a completely solid state altimeter developed by Hoffman and will be used in the Navy's S-3 Aircraft.

1972 There presently are two ARINC-TSO-87 commercial altimeters in general airlines use. These are the Collins AL-101 and Bendix ALA-51. These equipments are of the FM/CW (counter type) with operating range of minus 20 feet to 2500 feet. A few foreign airlines (SAS-SWISSAIR) use the SCR-718E and F for pressure pattern operation over water. This operation will probably continue since the will be unaffected by the FCC frequency rulings.

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B. NAVIGATION - WEATHER RADARS

The background of all radar developments is provided in this section since aircraft radars used by the military for surveillance, navigation and fire control also serve the purpose of weather radars. In the 1953 to 1958 time period the AN/APS-42 was provided with a pencil or fan beam and operated in the 3 cm band thereby providing improved weather detecting capabilities. This was followed by the AN/APN-59 radar with improved resolution, reduced size and weight. Today the most recent version is the AN/APQ-122. The prime goal of the development was to increase reliability by using solid state techniques. This radar operates on 3 cm and provides weather detection, ground mapping and beacon interrogation and response. The AN/APQ-122(V-1) version is a dual frequency (1 and 3 cm) and installed in the C-130 Adverse Weather Air Delivery Aircraft. The most widely known commercial weather radars are the following: Collins - WP-103; Bendix RDR1A used by Braniff in DC-6 and in 1970 RDIF used in all DC-10 except VAL, RDR-1D, RDR-1E, RDR-1F, RDR-100, RDR-110 and RDR-120; RCA - AVQ-10, AVQ-20, AVQ-30, AVQ-45, AVQ-46 and AVQ-55. Commercial radars employed in military aircraft are: Collins - WP-103 is used in the C-7, C-131, T-29 and T-39; Bendix RDR-1D is used in the VC-137 and VC-140; Bendix-RDR-1E is used in the C-9. Table 7 is a chronological list of significant background in the development of Weather Radars. Additional background on Weather Radars and their importance is in Appendix 2 on Meterology.

TABLE 7 AVIONICS - WEATHER RADAR, BACKGROUND

1886 Heinrich Hertz demonstrated that radio waves were reflected from solid objects.

1904 Hulsmeyer, a German engineer, was granted a patent in several countries on a proposed way of utilizing radio wave reflection in an obstacle detector and navigational aid for ships.

1922 A.H. Taylor, L.C. Young, NRL detected a wooden ship using CW wave interference radar with separate receiving and transmitters.

1925 Breit and Tuve, Carnegie Institute, utilized pulsed ranging for measuring the height of the ionosphere.

1930 June, L.A. Hyland, NRL detected aircraft by wave interference effect.

1930-1940 British, U.S. France and Germany continued exploitation of the radar concept independently and simultaneously.

1934 - 1938 The British Air Ministry set up a Committee for Scientific Survey of Air Defense. The committee proposed a plan for detection of aircraft by a pulse method submitted by Sir Robert Watson-Watt. The first experimental radar system of the type suggested by Watson-Watt was set up on an island off the English east coast. Work began on establishing a network of five stations about 25 miles apart to protect the Thames estuary. System operated at 22 and 28 MHz. Later used to plot V-2 rockets and was instrumental in success of the Battle of Britian. British successfully demonstrated first airborne radar during fleet maneuvers. System was an Air to Surface Vessel (ASV) for ship detection.

1936 Army Signal Corps tested its first pulse radar. Range 7 miles.

1938 (November) U.S. Army extensively tested a radar position finding equipment for direction of anti-aircraft guns and searchlights. This set went into quantity manufacture as SCR-268. Also used to track corner reflectors on weather balloons to determine winds aloft in bad weather. The SCR-268 was later replaced by SCR-584 for automatic tracking of aircraft for gun directing. The SCR-584 was used to track weather balloons plus PPI was used for storm detection.

1939 (Early Spring) A radar designed and built by the Naval Research Laboratory was given exhaustive tests during battle maneuvers, installed on the U.S.S. New York. The first contract for commercial manufacture of these sets was let as a result of these tests. System designated CXAM.

1939 (June) A British experimental Aircraft Interception (AI) radar was operating. This set was demonstrated to the Chief of the RAF Fighter Command in August. The Air Ministry requested 30 systems be installed in aircraft in next 30 days.

1939 (September) All 30 systems had been installed before the end of September. Four were ready the day the war broke out.

1939 (November) The U.S. Army demonstrated a long range early warning aircraft detection set to the Secretary of War. A contract for the production of this set, SCR-270 and SCR-271, was let in August 1940.

1940 Radiation Laboratory Massachusetts Institute of Technology formed.

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1940 Britain emphasized that wavelengths shorter than 1.5 meters would have to be used in airborne radar if sharp radar beams were to be produced. The radar work of American and British laboratories was combined by agreement of the two Governments.

1940 Randell & Boot, 10 cm 1 KW magnetron demonstrated in US by British Technical Mission.

1940 (4 January) First U.S. microwave equipment successfully operated at MIT Radiation Laboratory.

1941 (10 March) U.S. successfully tested a breakdown model of an AI radar in a B-18.

1941 (Spring) U.S. Navy installed an experimental microwave sea search radar equipped with a PPI on destroyer U.S.S. Semmes.

1941 (30 June) Navy let first production contract for the radar demonstrated on the Semmes.

1942-1946 Development of ground based Long Range Radars and Height Finders AN/CPS-6B, AN/FPS-3 & AN/FPS-6 were used during war.

1942-1945 Principal wartime American microwave radar developed and produced were: SCR-717 (Navy ASG) which was a 10 cm system using a 30-inch parabolic reflector and PPI presentation; AN/APQ-13, AN/APS-15, a 3 cm radar with optional sector scan, PPI display and a cosecant-squared antenna; AN/APS-3 (or ASD) and AN/APS-4 (or ASH) designed and produced by Navy at 3 cm and equipped with 18 inch and 14 inch paraboloid antennas respectively.

1945 (30 June) A total of $2,700,000,000 worth of radar equipment had been delivered to the army and Navy.

1943-1947 U.S. Navy contract with American Airlines to determine utility of APS-10 for weather avoidance. Thunderstorm avoidance using a contoured display was first accomplished.

1944-1953 The AN/APQ-13 bombing-navigation radar developed and produced by Air Force-Western Electric. Used a 30 inch parabolic antenna with a cosecant-squared reflector and operated on a fixed frequency in the 3 cm band. This radar was used initially in the B-29's first bombings of Japan and missions throughout the Far East. One of these radars was modified by Army Air Corps engineers at Wright Field using an "A" Scope and Delay circuits. To differentiate between ground clutter and storm display. This became the first airborne weather radar. Later Air Force modification was made to provide ground operations with a Weather Radar Storm

Detection capability. This modification involved the change of the radar pulse length, squared reflector and recentering of the transmitter-receiver dipole element to achieve a pencil beam. This provided improved terminal forecasting of severe weather conditions at military airfields for air base installation protection, safety and greatly increased aircraft traffic in the area. The first installation became operational in July 1945 at Davis-Monthan AF Base, Tucson, Arizona. The third day of initial experimental operations at this B-29 aircrew training center resulted in the saving of one B-29 with full aircrew and two instructors during very violent thunderstorms which lasted about 15 to 18 hours. This B-29 had a direct-strike by lightning and had its radio and radar equipment completely destroyed except for a back-up radio receiver located in another part of the aircraft. This provided a contact with the aircraft via the D-M AF Base Control Tower and a field-phone to the weather radar (AN/APQ-13A Mod) installation on the roof of a parachute tower. The 2nd Air Force made a special note of this event. Several of these installations were given to the U.S. Weather Bureau to operate and provide on-job-training of their personnel in this new-act of Weather observing and forecasting. Later, United Airlines began their efforts to adapt the airborne modified version AN/APQ-13 for their version for their commercial airline use for storm avoidance and safety of flight.

1952 UAL contracted for installation of RCA radar - first civil airline to be equipped.

1954 Bendix RDRIA used in Braniff DC-6. Collins WP101.

1954 RCA AVQ10 used by United Air Lines.

1945-1953 A radar developed and produced for Air Force use during this time period was the AN/APS-23. This system used a 60 inch semi-parabolic reflector and operated on a fixed frequency in the 3 cm band. This radar was used in B-50, B-36 and B-47A thru B-47D aircraft. The AN/APS-23 by the addition of the AN/APA-44, a ground position indicator and computer became the AN/APQ-24 used to guide the B-36 and B-50. The AN/APQ-23 plus the AN/APA-59 and other modifications with optical sights became the K-Series Bombing System for the B-47.

1950 SAGE (Semi-Automatic Ground Environment) Function of recognizing and plotting aircraft tracks was carried out automatically by electronic digital computers in lieu of an operator.

1953-1958 The AN/APS-23 was improved to provide a tunable capability in the 3 cm band. This plus other improvements for reliability and maintainability became the AN/APS-64 and was used in the B-47E, RB-47H, and B-52A thru B-52D aircraft. Also, during this period a radar system was developed and produced for use as a navigation aid and weather detection. This radar the AN/APS-42 provided a pencil or fan beam and operated on a fixed frequency in the 3 cm band. This radar was widely used in such aircraft as C-54 C-97, C-121 and C-124 aircraft.

1957-1959 RTCA-FAA-Aeronautical Radio-industry standardization of performance and form factors.

1958 A requirement for reducing the size and weight and improving the resolution of the navigation and weather detection capability of the AN/APS-42 radar resulted in the development and production of the AN/APN-59 radar. This radar used a 30 inch dish antenna for improved resolution and operates on a fixed frequency in the 3 cm band. It also provides a beacon capability and is used in C-130, C-133, C-135 and C-141 aircraft.

1960 Introduction of direct view storage tube that enables the pilot to view the radar in a bright cockpit.

1970 Military developed inertial navigation provided civil users with an adequate vertical reference for 300 mile long range radar.

1970 The most recent radar development for navigation and weather detection is the AN/APQ-122. The V-5 version of this radar is specifically designed to replace the APN-59. The prime goal of this development was to achieve much greater reliability through the utilization of solid state devices. This radar is in the 3 cm band and provides weather detection, ground mapping and beacon interrogation and reception. The V-1 version of the APQ-122 is a dual frequency radar (1 cm and 3 cm) and is installed in the C-130 Adverse Weather Aerial Delivery Aircraft.

B. NAVIGATION - INSTRUMENT LANDING

Early development of instrument landing systems was done by the Bureau of Standards and Department of Commerce using the radio range marker beacon and the altimeter. Early Air Force developments used two low frequency omni-directional locator stations, marker beacon and the radio compass. This AIA system was flown by Hegenburger and Crane at Wright Field over the period 1932 to 1937. Development and investigations of several systems covering different frequencies

up to and including microwave (3000 MHz) were conducted at Wright Field and evaluated by AAF, CAA and other national agencies between 1937 and 1941. As a result of these tests and developments it was agreed to use the SCS-51 landing system utilizing a 100 MHz Localizer, a 300 MHz Glide Path and a 75 MHz Marker Beacon. The specification for the SCS-51 Landing System was issued by the Army Sig Force 17 January 1941. This became standard landing system and over 500 ground stations and 18,000 airborne systems were procured for use all over the world. This is essentially the same system used today. This system required careful siting of the localizer and glide path antennae to prevent reflections from hangars and other reflecting structures such as ship's super structure and mountainous terrain. However considerable investigation of improved airport lighting systems for approach zones and runways together with improvements in the quality and reliability of ILS resulted in lowering weather minima for instrument landing to 1200 feet runway-visual-range and 100 ft decision height in 1966. Additional improvements in ILS have been proven feasible to permit reduction of weather minima to zero decision height and 700 ft RVR with properly equipped aircraft. In 1968 the FAA, under a joint program with the USAF, conducted a series of flight evaluation under simulated Cat. III conditions using a C-141 aircraft which had been especially configured to investigate Cat. III landing operations. This demonstrated the feasibility of Cat. III landing of a heavy aircraft.

In 1963 as the result of earlier Air Force and FAA work the FAA initiated development of a scanning beam microwave landing system (MLS) which was designed to promote guidance through approach, landing, and roll out. This development, known as Advanced Instrument Landing System (AILS) was the forerunner of later microwave landing systems. In 1965 the Air Force developed a microwave landing system AN/TRN-27 and AN/ARN-97, a portable system, for use in S.E. Asia. Versions of this system were approved by FAA for use by commercial airlines. A microwave landing system AN/SPN-41 was developed by the Navy for the USS Independence and is now being procured.

On 17 November 1971 the FAA released a five year program plan for the development of a microwave landing system. The plan was developed by a joint DoD/NASA/DoT planning group as a follow on to extensive work of the Radio Technical Committee for Aeronautics SC-117.

It is also significant to mention the Air Force has developed and used at many bases the GCA,a Radar Talkdown system. This is being used by the Air Force and at some civil airports.

Future activity in this area will be the development, evaluation, certification, and installation of the FAA Microwave Landing System.

Table 8 is a chronological list of significant background of development of Instrument Landing Systems.

TABLE 8 AVIONICS - INSTRUMENT LANDING SYSTEM, BACKGROUND

1929 (24 September) J.H. Doolittle of the Guggenheim Fund made the first instrument landing in history using a system comprised of a radio range localizer, marker beacons and an altimeter. The system was developed in 1928 by the Bureau of Standards for the Department of Commerce.

1931 (5 September) M.S. Boggs, at College Park, Maryland, performed the first blind landing using a Bureau of Standards system which provided guidance in a vertical plane (glide slope) as well as the previously flown radio range localizer and marker beacons. This operation included a complete monitoring system.

1932-1937 Army Sig.Corps developed AIA Instrument Landing System consisting of two low frequency ground locators mounted in jeeps, and two marker beacon transmitters. The aircraft equipment consisted of the radio compass and marker beacon receiver. Over 400 ground stations were procured and used. Many Air Corps pilots were trained on this system. At first, the Air Corps developed Kreusi E-4 radio compass was used. These were later modified by Army Sig Corps personnel at Wright Field to prevent reversal of indication. The Army Air Corp developed the SCR-186-T5 (Messer Jones Patent) which was an add on box using the SCR-183-tuned radio frequency receiver. In 1936 the SCR-186-T6 Radio Compass was developed using the MesserJones circuit This was a high performance high sensitivity, selectivity, direct frequency calibrated, 150-2000 KHz single unit, superhetrodyne radio compass which became the SCR-242 and 200 were procured. In 1937 the Sig Corps specification for the SCR-269 automatic bearing radio compass was issued and these were procured and installed in all aircraft used during WWII in B17, B24, B25, B26, P-38, P39, P40, P51, C46, C47 and C54. Various versions of this type automatic radio compass both military and commercial are widely used in Military, Civil Transport and small aircraft thru 1972 and probably will continue for many years.

1932 (9 May) Capt. A.F. Hegenburger, Army Air Corps at Wright Field, Ohio, made the first blind solo flight on instruments for which the Collier Trophy was presented to him.

1933 Over a hundred blind landings were made on the Bureau of Standards system at Newark, New Jersey.

1934 The first visual landing beam course indications were provided on a cross pointer instrument.

1936 The Bendix Radio Corporation in cooperation with United Air Lines and with the assistance of the Bureau of Standards tested the first VHF localizer.

1937 (23 August) First wholly automatic landing in history made at Wright Field, Ohio by Capt. Carl J. Crane inventor of the Air Force AIA System. Capt. George Holloman, pilot, and Raymond K. Stout, project engineer.

1937 - 1938 Over 3000 hooded landings were made in a Boeing 247 and a Douglas DC-3 by pilots of various airlines, Army, Navy and the Bureau of Air Commerce using the autopilot for attitude control with the pilot interpreting the displays and making slight control adjustments.

1940 - 1941 Early Microwave landing system (2600 to 5000 MHz) test at WPAFB, by Sperry Gyroscope and the USAF.

1941 Army Sig.Corps developed SCS-51 (110-330MHz) ILS. This became the first instrument landing system to provide a "tactical" capability used a five loop Alford antenna array for localizer and an earth mirror (reflective) glide slope. The ground system was carried in a truck and a trailer. The airborne system was the first to provide for direct autopilot coupling. 500 ground stations procured from ITT and installed at airfields all over the world. Over 18,000 airborne systems procured. (This system has been standard and is expected to be standard until the Microwave Landing System is installed in 1975.)

1946 - 1965 Prolific effort by the industry (Internationally) to develop microwave components and system concepts for instrument landing systems.

1951 The US Navy started a development program to achieve an automatic landing system for carrier operations. The SPN-10 system evolved from this development effort and is in use today on carriers.

1962 - 1966 USAF Control-Display Factors program included 10,000 hooded approaches and landings to validate control, display and piloting procedures for low visibility approach and landing for large transport aircraft such as the SST.

1962-1966 FAA All Weather Landing Program using DC-7 aircraft tested, evaluated, and demonstrated automatic and hooded manual landings using conventional ILS and radio altimeter guidance information at many runways in U.S.

1965 (September) USAF given the responsibility for a tri-service program to develop a microwave tactical landing system for military operations in Southeast Asia. This program (Interim Remote Area Terminal Equipment) led to production of the AN/TRN-27 and AN/ARN-97 a portable ILS.

1966 FAA approved operators of civil air carriers to use weather minima of 100 ft decision height and 1200 ft RVR using improved ILS and runway lighting.

1967 (June) As a follow on to the FAA experimental AILS landing system the Army awarded a contract to Airborne Instrument Lab. for an exploratory development model of a tactical landing system using mechanically scanned antennas and transmitting at 16 GHz. This was followed up in (1971) by the procurement of full "mil-spec" hardware for operational testing.

1967-1970 Advanced electronic cockpit displays using cathode ray tubes were developed for the SST by Boeing to display remoted television scenes of the runway combined with symbology for normal flight instrument functions. Hi-resolution, forward screening radars were also developed by Texas Instruments and Maxson Electronics to display the forward perspective view of the runway for use as an independent landing monitor during approach and landing. Head-up cockpit displays were developed by Sperry and evaluated by FAA in 1967 for use in low visibility landing, improved versions of these systems have been developed by others and new designs of head-up displays continue to be investigated and tested by FAA.

1968 Radio Technical Commission for Aeronautics formed Special Committee 117 for the "development of a precision guidance system concept for approach and landing, and an associated signal structure. This concept and signal structure satisfies the various operational needs of the several classes of users."

1968 Joint FAA/USAF all weather landing test program using a C-141 aircraft completed evaluation of experimental, Cat III, landing system at FAA test facility at NAFEC. Demonstrated feasibility of all weather landing by heavy jet aircraft using ILS guidance.

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1968 AN/SPN-41, a microwave scanning beam landing guidance system, was evaluated by the Navy on the USS Independence. A version of this system called C-Scan is now being produced by AIL Division of Cutler-Hammer for the Navy.

1971 FAA awarded contract for development of U.S. manufactured Cat. III, ILS ground guidance equipment. This equipment is a significant improvement over the original ILS, because it incorporates solid state electronics, independent monitoring and computer logic for switching to back-up transmitters.

1971 (November) Release of National Plan for a five year program for the development of a Microwave Landing System. The plan was developed by a joint DoD/NASA/DoT planning group as a follow on to the extensive work of RTCA, SC-117 of a provisional signal format and system concept for a new system.

1972 USAF using Collins Radio R1755/ARN with 40 channel Localizer Glidepath. The localizer glidepath and marker beacon are completely solid state mounted in one unit weight 6.25 lbs. for F111

TABLE 9 AVIONICS - GROUND APPROACH SYSTEM (GCA), BACKGROUND

1943 AN/MPN-1, (GCA), Army Sig. Corps - MIT Radiation Lab, ITT, Gilfillan; developed system, gained its fame during the Berlin Airlift in 1948. During one 26 minute period 26 aircraft were landed safely under GCA.

1948 AN/CPN-4 was developed as a follow-on to the AN/MPN-1 and provided the first direct readout from the GCA Radar Scope.

1952 AN/MPN-16 development separated the Radar (PAR - Precision Approach Radar) from the rest of the facility.

1954-1956 Army A.C. - Gilfillian developed AN/FRN-42 forerunner of AN/TPN-8.

1957 AN/TPN-8 - Light weight GCA developed jointly by Navy, Marines and Army A.C.

1959 (September) AN/MPN-13. The GCA range was extended from 40 to 60 miles and provided high altitude coverage close in.

1962 AN/FPN-501 RAPCON version with 120 mile ASR developed by CANADA.

1963 AN/MPN-14 Developed by USAF. Added 3rd Van to move operations center away from equipment vans and provide space for more stations.

1965 AN/TPN-17 Mobile GCA developed for operations in SEA.

1966 AN/TPN-8 updated to TPN-18 by adding IFF.

1969 AN/FPN-52 Solid State GCA developed by the Navy.

1971 Electronic Scan Radar (PAR - Precision Approach Radar) tested by the Navy at Patuxtent River.

B. NAVIGATION - OMEGA

The Omega, low frequency, below 100 Hertz, is a long range navigation system developed by the U.S. Navy that has possibility for world wide navigation and time reference from a few ground stations. The navigation system is useful for aircraft, ships as well as submarines. Four of these ground stations are in operation now and four more installations are planned. The estimated cost of a ground station is approximately $10 Million each. The estimated cost of aircraft equipment is between $10K and $50K. Product improvement, utilizing solid state and microcircuit techniques may greatly reduce costs and increase future use.

Table 10 is a chronological background of significant events occurring in the development of the world wide navigation system, OMEGA.

TABLE 10 AVIONICS - NAVIGATION, OMEGA, BACKGROUND

1937 British developed GEE System.

1942 GEE System operational in Britain.

1942 Evolved into Loran "A" in U.S. at 1750-2000 KHz.

1943 Operational Loran "A".

1945 Development of 180 KHz Loran started by MIT Radiation Lab.

1946-1947 Canada Field Trials 625 ft towers.

1946 Cyclar by Sperry 180 and 200 KHz.

1949 Cytac - essentially Loran C.

1950 Radux concept developed for NAVY (NEL).

1951 Cytac demonstrated to USAF.

1952-1954 Rho-Theta "Navarho" 100 KHz.

1952-1954 CW 100 KHz system used by British Postal Office.

1957 First Coast Guard Loran "C" chain set up.

1947-1957 MIT Rad Lab closed, Dr. Pierce and Mr. Woodward moved to Cruft Lab at Harvard and continued long range navigation work with Navy.

1953 British used 60 KHz with precision crystal standard; found time could be measured to one part in 10^{10}.

1954 Rugby station operated on 16 KHz 2 parts in 10^{11}.

1955 Radux - Omega system composite evolved (CW) 40 KHz + 10 KHz to resolve lane ambiguities.

1955-1962 Omega experimental work continued (5000 mile baselines).

1959-1962 VLF Radio grid system having radio security characteristics developed by Army S.C. and Motorola. Evaluated but not adopted.

1962-1965 Buships (NAVY) developed Omega implementation plan.

1965 FAA developed Loran-C hyperbolic coordinate converter.

1966-1967 Army S.C. - Motorola Secure System (LORAN F) field evaluated. No further action taken for non-technical reasons.

1967 Four Omega Stations (Trinada, Hawin, Norway & Main) in operation on 10 Kilohertz.

1967 FAA developed Omega navigation computer and crossed loop airborne antenna.

1968 Airborne Omega Equipment used AN/ARN-99 Airborne Omega Receiver.

1972 Four new OMEGA stations expected to be put into operation.

B. NAVIGATION - NAVIGATION SATELLITE

Significant background in the development of Navigation Satellites is shown in Table 11.

TABLE 11 AVIONICS - NAVIGATION SATELLITE (NAVSAT), BACKGROUND

1959 Development and utilization of a radio telemetry and ranging system which permitted the interrogation and tracking of orbiting space vehicles.

1964 Low altitude orbital doppler experiment in a polar orbit led to Navy TRANSIT system.

1965 Initiation of Integrated CNI studies.

1966 NASA-ERC study of a concept for navigation and traffic control over North Atlantic by use of satellites in synchronous equatorial orbit.

1968 Concept definition studies for 621B system. Studies resulted in establishment of equipment definition and experiments.

1968 ECOM Tactical system effort to provide theater common grid navigational compatibility to tactical aircraft and ground forces.

1971 Design study of a single channel receiver and inertial interface implemented to permit airborne navigation with respect to a form satellite constellation configuration. Development of computer software with the capacity and real time capability to navigate with respect to satellites or ground or airborne emitters that report their position or ephemerides.

C. IDENTIFICATION

Developments of equipments in this area by the military stemmed from the need to identify the aircraft as to whether it was a friend or foe. Significant early developments depended on early radar developments. In the 1940 to 1945 time period the dependence on radar was eliminated by using an Interrogator and Transponder. In 1953 the CAA and Military agreed to share the Mark X, Selective Identification Feature (SIF) and this system was used to interrogate the aircraft for Traffic Control and Anti-Collision warning purposes. In 1961 the first US Standards were agreed to between DOD and FAA.

In 1963 the standards were revised, requiring an increase in automatic identity and altitude coding of the Air Traffic Control Radar Beacon System (ATCRBS) for use of the Air Controller. Subsequent developments are intended to improve the antenna characteristics. The development of the AN/APX-101 all solid state transponder is nearing completion. Table 12 is a chronological background of significant events in the development of Identification equipment.

TABLE 12 AVIONICS - IDENTIFICATION (IFF), BACKGROUND

1925 Principle of pulse ranging first used, Breit and Tuve (Carnegie Institute of Washington) for measuring the height of the ionosphere.

1939 Army develops short and long range detection radar (SCR 268 and SCR 270 respectively). The development of radar extended the detection range of ships and aircraft but radar echoes from these vehicles carried no national insignia; hostility could not be recognized. Rotating reflectors and reflective and absorbent coatings on propellors were used to provide a "signature" variation in reflected signals.

1940 Mark I IFF, which was reported operational by 1940, was the first of a series of radar beacons developed by the British. The Mark I used active rather than passive elements and consisted of a regenerative amplifier and a small broad band antenna with reduced directional capabilities. Upon receipt of a radar pulse at the antenna, the amplifier would oscillate and return a powerful pulse near the radar frequency. The received echo at the radar site appeared larger and actually masked the normal radar return.

1940 Mark II, operated similarly to Mark I with the exception that it was capable of sweeping two or more radar frequency bands. The problem with the Mark II was that it could not separate itself from the normal radar return. The beacons (SCR 535, SCR 595) were produced under Army contracts by Philco and Hazeltine. The system was placed in operation by U.S. in 1941.

1941-1945 The dependence on radar was eliminated with Mark III and two new components, called the interrogator and the transponder were added. The interrogator was used to challenge the transponder in the same manner as radar. The transponder was still mechanically swept-tuned over a frequency range of about 160 MHz to 170 MHz. The transponders (SCR 695) were produced by Stewart-Warner under Army contracts. The interrogators were identified as RC-148, RC-151, RC-150, RC-136, RC-127, RC-184, SCR-527 and SCR-588.

1940-1945 The Mark IV system development was started during World War II. This system did away with mechanically swept tuning. The operating frequency was increased to 470 MHz for the interrogation and 493.5 MHz for the transponder return which was selected from one of ten coding discs. A visual indication signal method was also provided, whereby the pilot could respond to "tone" interrogation by shooting off colored flares. The Mark IV system was never placed in operational use.

1942-1946 A Combined Research Group undertook development of the Mark V/UNB (United Nations Beaconry) from late 1942 to early 1946. The single pulse interrogation was changed to a dual pulse method in which the spacing between pulses was selected. The Mark V transponder was capable of being switched to one of three interrogation modes. Mode 1 was to be used for initial identification. Modes 2 and 3 were intended to be used for many purposes, such as personal identification, flight leader identification, squadron identification, and navigation aid. The reply by the transponder was a single pulse for all three modes except during position identification (I/P) and during an emergency. I/P was indicated by the transmission of a pair of pulses, and for emergency by a series of four pulses. Mark V did not reach the production stage by VE Day, and a new IFF system was being developed (MK VI).

1945 The emphasis in IFF shifted to meet the requirements of the Pacific Theater. This called for simplification of the existing Mark V system, but the new IFF called Mark VI never was developed. The next IFF was thereafter called "MARK X", although there were no other developments - VII to IX.

1948-1950 The MARK X IFF system resembled the Mark V. The main features of Mark X were the single L-Band (1030 MHz for interrogation and 1090 MHz for reply) frequency of operation, the increase of I/P pulse spacing. Modes 1 and 3 replies as a single pulse, and Mode 2 replies by a series of four pulses. Also, the same interrogation pulse pairs were used for Modes 1, 2 and 3 respectively. Although the transponders and interrogators operated at frequencies 60 megacycles apart, they had the ability to be adjusted for operation in any one of the allocated IFF frequencies. The AN/APX-6 Mark X transponder was produced in large quantities by Hazeltine and Stewart-Warner, and placed in use by the Air Force and Navy in 1949.

1953-1970 Mark X SIF is an extension of Mark X with a Selective Identification Feature (SIF) added to the system. This addition changes only the reply of the transponder. The reply of SIF takes the form of a coded train placed inside framing (bracket) pulses.

The code itself consists of 13 bits which are 0.45 microseconds wide, placed 1.45 microseconds from each other. The Mark X with the SIF added, since 1959, has been used in most military aircraft. The AN/APX-25 is a typical transponder and approximately 100,000 equipments were subsequently produced. The capability of changing the reply code permits discrete replies to be selected from several possibilities for each mode of operation. The ability of this system to "label" the replies of particular aircraft or types of aircraft led to the adoption of this IFF system as an aid to aircraft traffic control by both the civil and DoD agencies. This system was placed in military use during 1956-1959 Period.

1953 Military agrees to share Mark X (SIF) system with CAA for common beacon system. Under civil usage the system became known as the Air Traffic Radar Beacon System (ATCRBS).

1957 First "Memorandum of Understanding" reached between DoD and CAA for peacetime use of common beacon system. Stewart-Warner, Wilcox, RCA and Collins developed transponders for civil airline use. (Initial installations were made during 1957.)

1959-Present The Mark XII IFF System is an extension of the Mark X (SIF) which was an evolution of the Mark X system. The Mark XII system interrogates aircraft by the use of a varying type of code. This type of code interrogation makes deciphering by enemy aircraft highly improbable. Production of Service Test Models started in 1960.

1961 First US Standards for Common System Characteristics agreed upon between DoD and FAA. President directs FAA to set up "Project Beacon" early in 1961. Late in 1961, the President asked FAA to begin carrying out the recommendations of the report. The recommendations included automatic altitude reporting to the ground controllers and an increase of identity coding capability of Air Traffic Control Radar Beacon System (ATCRBS).

1961 FAA developed first General Aviation Transponder (GAT) low cost light weight and, with the exception of a transmitter tube, all solid-state.

1963 FAA developed SLATE (Small Light-weight Altitude Transmission Equipment) the first transponder economically feasible for general aviation usage with automatic altitude reporting capability on Mode C and 4096 reply codes on Mode 3/A.

1963 US Standards for Common System characteristics amended to include automatic altitude reporting, increase of identity coding for Mode 3/A, side lobe suppression feature and other system

improvements. "Memorandum of Understanding" between DoD and FAA reached.

1963-1975 The AIMS* program was established in 1963. The program, directed by DoD, is the first major equipment/subsystem effort involving tri-service implementation and managed by a single department (the Air Force in this case). It involves participation by the Department of Defense in the Federal Aviation Agency's plans for improving the Air Traffic Control System, through compliance with the updated US National Standards and the "Memorandum of Understanding" referred to above. The military investment is in excess of $750,000,000.

1967 Establishment of the Beacon System Interference Problem Subgroup. Chaired by FAA membership consists of DoD personnel and representatives of common carriers.

1967-1970 The development of diversity (Hartlobe) transponders was begun by the Navy and the Air Force in 1967 to improve transponders to overcome aircraft antenna shadowing problems thereby improving antenna coverage. (A diversity transponder is equipped with two antennas and replies via the antenna which received the stronger interrogation.) Equipment contracts exist today between Air Force and Hazeltine (AN/APX-90), Air Force and Stewart Warner (AN/APX-89), Navy and Bendix (AN/APX-72) and Air Force/McDonnell Douglas F-15 contract with Teledyne (AN/APX-101). In addition to being a diversity transponder, the APX-101 is the first completely solid state transponder (including the transmitter).

1969-1971 Development of an antenna mounted solid state receiver transmitter to eliminate antenna cable losses was begun by the Navy with Bendix and the Air Force with Teledyne.

1970 FAA initiated development of DABS (Discrete Address Beacon System). Features of the system include tracking data and specific aircraft address. The address feature provides natural data-link for traffic control purposes.

*The acronym AIMS is derived as follows:
ATCRBS (Air Traffic Control Radar Beacon System)
IFF (Identification Friend or Foe)
Mark XII Secure Identification System
Systems (reflecting the Many AIMS configurations).

1971 Development of a retro-directive transponder antenna was begun by the Air Force with Bendix.

D. COMPUTERS - ANALOG & DIGITAL

Analog navigation computing devices offer rapid calculations of a fixed dead reckoning problem, but are poor from the standpoint of flexibility. The requirement to change the "program" is tantamount to redesign and retrofit. Digital computers provide rapid solutions to the entire range of aviation applications and are highly flexible. Modifications are accomplished through software (programming) changes, rather than hardware retrofits.

The future for analog devices lies in the hybrid, a synthesis of the best features of analog and digital computation. Such a system offers optimal performance, flexible control and reprogrammability in the general purpose digital computer, and high speed computations as required from analog devices. The future application of digital computers is unlimited. The integrated circuit computers available today, resulting from large investment by the military and civilian enterprises, are reliable, versatile and compact. They are cost effective in comparison with other methods used today.

Associative processors will prove highly valuable in applications requiring rapid comparison and correlation of data. The added hardware cost is justified in areas of air traffic control, collision avoidance and moving target indicating radars, where the associative processor offers much faster speeds than the conventional computer.

Significant applications are to aircraft flight stability control, propulsion and fuel control, navigation, identification, communication, automatic status display, system checkout, airline reservation, automatic cargo sorting and handling, automatic machine and manufacturing operations and handling, training, simulation, etc. The computer technology is the key to automated systems and to the design and production of such systems. Significant background in the development of Analog Computers is shown in Table 13. Significant background in the development of Digital Computers is shown in Table 14.

TABLE 13 AVIONICS - ANALOG COMPUTER, BACKGROUND

1876 Lord Kelvin describes a special analog computer.

1925 Vannevar Bush begins study of analog computer.

1930 Vannevar Bush develops differential analyzer.

1942 Vannevar Bush develops more elaborate machine, M.I.T.

1941-1945 Electronic differential analyzer.

1944-1945 Air Position Indicator (API) Type AN-5841-1 was developed by Eclipse-Pioneer Div., Bendix Corp. and used in the B-25 and B-29.

1950 CAA developed Pictorial Computer (several versions by industry one in-house) and course line computer (in-house). Used VOR-DME signals. Design based on tube technology and therefore too large.

1950 AN/ASN-7 Analog Navigation Computer, Ford Instrument Company, installed in USAF, F-100, F-101, F-105 and KC-135 aircraft.

1950-1951 Ground Position System. Type (C-1) A-1 was developed by Cook Research Lab.

1953-1954 Computer Set, Latitude and Longitude AN/ASN-6 was produced from Ground Position System Type A-1 by Ford Instrument Company. KC-135, F-101.

1956 AN/ASN-9, Analog Navigation Computer.

1959-1964 AN/ASN-25 Track-Oriented DR Computer, General Precision, Inc. (fully transistorized), tested in F-100F in 1961-1962, tested in F-105 in 1963, procured for all Royal Danish AF F-100's.

1959 AN/ASN-39 developed by Navy, was a forerunner of the AN/ASN-41 analog computer.

1960 Computer Set, Navigational AN/ASN-35 (Alongtrack-crosstrack) was developed by Canadian Marconi Co. C-130, C-141.

1961 AN/ASN-41 Navy developed analog computer used in A4E, A7A, RF-8G, WC-121.

TABLE 14 AVIONICS - DIGITAL COMPUTER, BACKGROUND

1944 IBM-Harvard Mark I calculator.

1945-1950 ENIAC (first authentic electronic digital computer) Mauchly & Eckert, University of Pennsylvania.

1954 USAF-BTL developed TRADIC, the first airborne general purpose transistor digital computer. Purpose of the development was to evaluate use of transistors in airborne radar bombing systems.

1957 First airborne general purpose operational digital computer, miniature tubes, part of (Hughes) MA-1 Mod VI fire control system of the F-106. 545 delivered to USAF.

1957-1960 USAF-Autonetics VERDAN transistor computer and digital differential analyzer (DDA) developed for Hound Dog, USAF.

1957-1960 AN/ASN-24 (Librascope), first transistor general purpose airborne digital navigational computer. Tested on C-131's flown on C-141's. Centaur version later flew with Surveyor and Mariner spacecraft. Contracts included AF33(616)5128, AF33(616)6659, USAF.

1959 HCM-300 (Hughes), germanium transistor, Polaris Mark I missile guidance, USN.

1961 USAF-Texas Instruments Company demonstrated first integrated circuit computer during October to audiences in Washington DC, Dayton and Los Angeles.

1964 USAF Minuteman II guidance computer flight tested. First aerospace computer to use integrated circuits.

1965 HCM-204 (Hughes) IRAM computer replaced MA-1 tube computer on F-106 fleet. About 324 of these integrated circuit computers were delivered, USAF.

1965 HDC-801 (Honeywell) ALERT computer - EC121, EB66, C-135, C-5A, USAF, NDC 1051A, 1060 (Northrop Electronics) C-5A, USAF.

1967 Magic 301 (Delco Electronics) SRAM missile guidance computer, USAF. D26J-103 (Autonetics) SRAM missile launch computer, USAF.

1967 AN/ASN-91(V) (IBM TC-2) weapons delivery computer, A-7D, E, AC-130E, USAF.

1968 D26J41 (Autonetics) Mark II Inertial Computer, F-111, USAF. 5400 (CDC) Phoenix Missile Control, F-111, USAF, CP-2 (IBM) Mark II Navigation, W/D computer, F-111, USAF.

1966-1969 CP898(AN/ARN-92) (Lear Siegler) LORAN C and D navigation computer, FAA.

1969 MICRO-D 1801 (ARMA) for LTN-51 Aircraft Inertial Navigator. About 600 quantity.

1969 Magic 311 (Delco) Carousel IV computer, used in Boeing 747's.

1970 AN/AYK-8 (Westinghouse) weapons delivery for B-57G, USAF.

1970 USAF-Goodyear developed Associative Data Processor, AF contract F33615-68-C-1555 and F33615-70-C-1294, total cost $750,000. Installed at FAA facility, McGhee-Tyson Airport, Knoxville, Tennessee for test

1971 2540 (Texas Instruments) electronic intelligence for F-4, prototype, USAF.

1971 AP-1 (IBM), central avionics computer, F-15, USAF.

1971 2520 (Texas Instruments) tactical electronic warfare computer, F-15, USAF.

1971 469 (CDC) Sprint AGM computer, US Army.

1971 1960 (Northrop Electronics) Undergraduate Navigation Trainer Computer, USAF.

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E. GUIDANCE SYSTEMS

Automatic guidance systems started with the development and use of the automatic pilots in aircraft. Early developments of guidance systems were applied to remote control of targets and drones. This involved the controlling of the propulsion system as well as operating other flight controls and landing gear, by radio control. During WW II war weary B-17's were modified for remote control and used to bomb German strongholds. More sophisticated systems were developed to guide and control missiles. During the war fire control systems were developed to aim the guns at enemy targets by radar. Other systems were developed to calculate the bomb trajectories, automatically guide the aircraft and drop the bombs on targets, with greater accuracy than previously obtainable. With the advent of higher speed and higher performance aircraft came the need for faster more reliable methods of control. Table 15 traces the significant background of adapting the aircraft to be flown by signals derived from computer processing of information obtained from various navigation system sensors as well as preflight plans stored in the computer. The background presented here is to show the large amount of technology that is available to control and guide the aircraft. Background research and developments in autopilots, stability augmentation, attitude and heading hold, airspeed control, altitude, inertial, radar, landing systems, gust alleviation, structural mode and vibration control, station keeping, hover augmentation, lift control, terrain following and avoidance, performance status indication and display, provide the know-how to automatically fly aircraft of all types from take off to landing. With the developments in integrated circuits and other solid state devices the use of dual, triple and even quadruple redundancy and fail safe circuitry provides the methods of accomplishing these functions with greater reliability and dependability, providing greater safety and comfort to the passenger and to other aircraft. Integrated Display of performance data provides the pilot with necessary performance data. With greater accuracy in station keeping and automatic landing during Cat III on parallel 2500' spaced runways, more aircraft can be landed, congestion and delays reduced and changes of collision minimized. The technology is applicable to all types of aircraft. The Boeing B-747 Jumbo-jet is an example of this technology. The complete integrated system, functions as a whole, self controlling, self correcting, self compensating as a modern aircraft must be. Control by other methods are a thing of the past. Built in "fail-safe" techniques, malfunction detection indication and recording devices provide for fast maintenance and greater airplane availability thus greater profits. The computer makes this possible. The rapid application to new aircraft permits attaining national goals by civil as well as military aircraft.

TABLE 15 AVIONICS - GUIDANCE SYSTEMS, BACKGROUND

1941 Autopilot-Localizer Mode. Developed by Sperry. Input was derived from Radiolocalizer Autopilot. Output provides Heading Steering.

1942-1943 Flux Gate Compass. Developed by Bendix. Input derived from Magnetic Field, Gyro stabilized. Output provides Magnetic Heading.

1942-1943 Gyrosyn Compass. Developed by Sperry. Input was derived from Magnetic Field Gyro. Output provides Magnetic Heading.

1944 Radar-Assisted Norden Bombsight. Developed by MIT. Input was derived from Radar, Gyro Visual. Output provides Steering, Bomb Release and Improved Accuracy.

1948 SNARK Guidance System. Developed by Autonetics Nortronics. Input was derived from Inertial, Celestial, Doppler. Output provides Steering Position. Flew 1952.

1949 Zero Reader. Developed by Sperry. Input was derived from VOR, ILS, Directional Compass, Vertical Gyro. Output provides Position, Attitude & Steering Data. Used multiple data and aircraft dynamics to give integrated display of position and attitude to command correct maneuver.

1950 Flight Director. Developed by Collins Radio. Input was derived from VOR, ILS, Directional Compass, Vertical Gyro. Output provides Position, Attitude & Steering Data. Used multiple data and aircraft dynamics to give integrated display of position and attitude to command, correct, maneuver.

1951 XN-2 Autonavigator. Developed by Autonetics. Input was derived from Inertial, Celestial. Output provides Position. Used Analog Computer, Acquired Stars in Daylight.

1955-1961 Army developed "building block concept" applied to Army SC-Sperry development of AN/ASW12(V) autopilot. Army proposed self-adaptive technique not included but later pursued by Industry.

1956 SCAN. Developed by Lear, Inc. Input was derived from Doppler, Heading, Air Data, VOR-DME, TACAN, DECCA, NAVARHO. Used Analog computer.

1956 ASQ-38 Bombing System. Developed by IBM, GPL. Input was derived from Doppler, K-Type Bombing System. Output provides Steering, Bomb Release. Used Analog computer.

1957 B-70 Nav System. Developed by MIT/Sperry. Input was derived from Doppler, Inertial. Output provides Position, Velocity, Attitude, wind, distance and time to go.

1956 AGM-28. Developed by Autonetics. Input was derived from Doppler, Inertial. Output provides Position, Velocity, Attitude. Used on Hound Dog Missile.

1959 INDOPS. Developed by Navy, Honeywell. Input was derived from Doppler, Inertial. Output provides Steering, Position. Bench Tested.

1960 B-58 Bomb-Nav System. Developed by USAF-Sperry, Ryan. Input was derived from Doppler, Inertial. Output provides Steering, Position.

1961 ALR-1 Attitude System. Developed by GPL, AC Spark Plug, Burroughs. Input was derived from Doppler, Inertial. Output provides Heading, Attitude, Position. Used to Stabilize High-Accuracy Radars.

1963 AN/ASB-12. Developed by Navy, Autonetics. Input was derived from Inertial, Radar, TV. Output provides Position, Velocity, Attitude.

1966 UPDATE. Developed by Navy, Honeywell. Input was derived from Inertial, NNSS (Satellite Range-Rate). Output provides Guidance, Position. Flight tested.

1966-1967 DIL. Developed by Litton, Kearfott Teledyne. Input was derived from Doppler, Inertial, Loran. Output provides Guidance, Position. Breadboard Designs Resulted in firm Definition for system.

1967 SIDS (Stellar Inertial Doppler System) developed by USAF-Litton. Input was derived from Stellar, Inertial, Doppler equipments. Output provides Position, Velocity. Evaluation Completed.

1967 Inertially Aided All-Weather Landing for CTOL. Developed by DoT-FAA. Input was derived from Inertial, Air Data, VORTAC, ILS. Output provides Guidance, Attitude. Flight Tests 1970 demonstrated suitability.

1968 Guidance System. Developed by Sperry. Input was derived from Loran, Inertial. Output provides Steering, Position.

1968 AMSA Task . Developed by USAF Autonetics, AC Electronics, GPL. Input was derived from Doppler, Inertial. Output provides Position, Altitude, Attitude. Flight Tested, Kalman Filter.

1968 SSCNS. Developed by Navy, AC Electronics, Collins. Input derived from Inertial, Radio-Celestial. Output provides Heading, Attitude, Position, Velocity, Kalman Filter.

1968 DIL. Developed by Litton. Input was derived from Doppler, Inertial Loran. Contract Award for Hardware.

1968 MARK II(FB-111). Developed by USAF-Autonetics. Input was derived from Inertial, Stellar Doppler, Radar, Visual. Output provides Guidance, Position, Attitude. Used Fully Mechanized Kalman Filter; Also Initializes SRAM Missile.

1968 C-5A Nav. System. Developed by USAF-Northrup, GPL Kearfott, Collins, Hoffman, United Aircraft Elliott. Input was derived from Inertial, Doppler, Loran, TACAN, Radar, Air Data. Output provides Guidance, Position. In Production.

1968 Developed by Northrup. Input was derived from Omega, Inertial. Output provides Guidance, Position. Under Study.

1968 B-747 Flight Control. Developed by Boeing-Sperry. Input was derived from ILS, VOR, Air Data, Accelerations. Output provides Flight and Landing Guidance. Fail Passive System.

1969 Apollo Guidance and Nav. System. Developed by NASA-MIT Instrument Labs. Input was derived from Visual, Inertial, Radar, Ground Data, (Telemetered). Output provides Guidance, Attitude, Position. Lunar Landing, 7-20-69.

1969 SIGN-III. Developed by Navy, Honeywell. Input was derived from Inertial, NNSS (Range-Rate Data). Output provides Guidance, Attitude. Strap-Down Inertial System.

1969 621B/Inertial Nav. System. Developed by TRW. Input was derived from Inertial 621B (psuedo-range and range-rate). Output provides Position, Velocity, Heading, Guidance. Flight Tested in 1970.

1969 Geo-Nav. System. Developed by Texas Instruments. Input was derived from NNSS (Range-rate), Ground Speed, Heading, Speed thru water. Output provides Position, Velocity. For Evaluation.

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1969 DC-10 Flight Control System. Developed by Bendix. Input was derived from ILS, VOR, V/G, Air Data, Radar Altimeter. Output provides Flight and Landing Guidance. Fail Operational. Dual-Dual Redundancy.

1969 L-1011 Flight-Control System. Developed by Collins, LSI. Input was derived from ILS, VOR, V/G, Air Data, Radar Altimeter. Output provides Flight and Landing Guidance. Fail Operational. Dual-Dual Redundancy.

1969 Aircraft Area Nav. Systems. Developed by Butler National, DECCA, Hughes, Litton, Collins. Input was derived from Radio Navaids, Inertial, Air Data. Output provides Position, Steering. Several Versions in Development and Test.

F. AIR TRAFFIC CONTROL

The Air Traffic Control System is the responsibility of DoT-FAA. The system as exists and as needed in the future has been studied and described in the Civil Aviation Research and Development (CARD) Report. The capabilities of the present and future system involves:

Data Acquisition: Primary & Secondary Surveillance Radars and Beacons.
Data Transmission: Primary, Secondary, Air & Ground.
Data Processing: Flow Control, Clearance Processing, Metering, Spacing & Separation Assurance.
Navigation: Enroute and Terminal, airborne, Ground Stations, Landing and Terminal.
Oceanic: Surveillance, Communications, Control and Navigation.
Flight Service Stations.
Training: Pilots, Controllers.
Weather Information: ground and airborne.

The basic components involved in an Air Traffic Control System are: aircraft; airports; navigation systems; communication systems including land lines, microwave links, data links with other Airports, Radars, Aircraft and Satellites; rules, procedures, training and people. The system covers the United States and interfaces with and must be compatible with foreign systems. This report covers only the background technology research and development which led to equipments used in the system and does not go into the background of safety rules, regulations, coordinating committees and standards which have been developed and applied nationally and internationally since 1925.

The equipments used in the present ground complex of the Air Traffic Control System have come directly from DoD developments but in many cases with joint cooperation of FAA going back to 1921 in early developments of the A-N Radio Range. The background of various equipments making up the present system relates to Air Traffic Control. Significant events in the technological background development of Communications, Navigation including Landing Systems, GCA, Tacan, etc. Identification, Computers, Automated Guidance Systems and Devices contained in previous sections of this report are applicable and make present and many proposed systems feasible. The technology background of microcircuit computers and various digital processing devices is based on DoD development and will be used more and more in future applications. The Associative Processor under development by USAF-Goodyear at a cost of approximately $1 Million and now being evaluated by FAA at McGhee-Tyson Airport, Knoxville, Tenn. is an example of a recent development which may be a significant advance in automatically reporting aircraft traffic, reducing controllers workload and relieving aircraft congestion. Examples of other efforts are: early DoD sponsored studies at Ohio State Univ. on ATC, Human Factors, Systems and procedures, early Volscan investigations, use of the SAGE system at Lexington for ATC experiments such as the SATIN program, the logic developed to track enemy aircraft, was the basis for NAS and ARTS tracking techniques and Joint effort under AIMS to standardize the Beacon as part of the ATC automation.

G. DEVICE TECHNOLOGY: Electronic Parts and Techniques

The military departments have supported the development of electronic devices, parts, techniques and manufacturing methods for many years. The primary purpose of these developments was to develop the technology necessary to satisfy military performance and environmental needs, to permit the design of equipments and systems which are reliable and meet military characteristic requirements. Programs for electronic device developments are coordinated by a DoD committee with representatives of NASA, DoT and industry. Palasides Corp maintains a secretariate to provide meeting place and to publish a document; Title: AGED Project Briefs. This document informs industry of the state-of-the-art of devices for use in designing new systems. This information prevents duplication of effort and speeds up the transfer of technology and introduction of new technology.

Electronic parts development - There are numerous significant advances in this area. Individual developments involve small amounts of dollars but are often the key to reliability and long life. Present aircraft would not be flying today without the development of parts which withstand higher temperature, are of greater reliability, performance and ruggedness and smaller in size. Data on these developments are available thru the AGED reports, see above. One outstanding example is in the area of integrated circuits and the tremendous pay-off resulting from this development. In striving to obtain more ruggedness and reliability the USAF in 1957 made many investigations to determine the feasibility of performing circuit functions in a solid block of material.

The program was approved by DoD in 1959. The birth of the integrated circuit industry can be traced to two Air Force developments which demonstrated, for the first time, production processes for making integrated circuits. These contracts were as follows:

AF-8913 - Westinghouse, $1,000,000 over the period May 59 - Jun 63.
AF-42210 - Texas Instruments, $1,600,000 over the period Sept 59 - Jan 63.

Additional contracts resulted in the first demonstration of computer aided design of integrated circuits, in development of passivation methods for silicon oxides and nitrides, and automated production and control of diffusion profiles. The results of these contracts were significant in developing production capability for solid state devices and integrated circuits. These contracts were:

AF-1395 - Norden Division, United Aircraft, $475,000, June 64-March 66.
F33615-68-C-1668 - General Electric, $98,000.
F33615-68-C-1483 - Motorola, $135,000.
AF33(100)-42509 - Motorola, $841,000, March 61 - Sept 66.
AF-2784, Fairchild, 216, June 65-Jan 67; AF615-1278, Fairchild, 257, Jan 67-Apr 69, demonstrated production readiness of various types of single metal oxide semiconductors, (MOS) devices, MOS arrays and complimentary MOS arrays.

In commercial aircraft today, solid state devices are replacing thermionic devices in avionic subsystems across the board. Light Emitting Devices (LEDs) are finding wide usage. Also digital electronics using integrated circuit logic are rapidly replacing linear circuits. For example, the Air Data Computer for flight management, an all new altimeter such as the AL-101, the auto-pilots, electronic displays, sensors, weather radar, electromechanical instrumentation, etc., all use many integrated logic circuits which

are a spin-off from the production capability advanced under the contracts listed above. Several representative commercial aircraft which use the IC's (integrated circuits) are Douglas DC10, Lockheed L1011, Boeing 747, Gulfstream 2, and Falcon 20. These commercial aircraft also use many linear integrated circuits in communication and in the servo control electronics. This high volume usage of solid state devices has resulted in more functional electronics in the airplane, less weight, less power consumption, and improved reliability of the avionic subsystems for less cost.

All new aircraft are increasing the use of MOS arrays for memory, multiplexing, A to D conversion, analog switching, logic and instrumentation. The MOS arrays are performing many new complex functions in commercial aircraft at moderate costs with greater reliability and use of less power.

Integrated circuits have pervaded all aspects of our economy not only in the business of building integrated circuits but also in building equipments to utilize them. The initial expenditure of $3.6 million in 1959 resulted in integrated circuit sales by industry of $191 million in 1966 increasing to $887 million in 1970. **The dollar sales of new equipments utilizing integrated circuits will be in the multi-billion dollar area.**

G. DEVICE TECHNOLOGY: Antennas and Radomes

Antenna technology is of particular concern to aircraft designers not only because of the number used on aircraft but in order to design the most appropriate one for the service intended. Of particular interest is developments in electronic phased antenna arrays, Table 16. Table 17 is a chronology of significant backgrounds in the development of radomes.

TABLE 16 AVIONICS - PHASED ARRAY ANTENNA, BACKGROUND

1958 Development by Navy-Hughes of AN/SPS-32 and AN/SPS-33 phased array in the VHF and S-Band frequency ranges. These were the first operational fixed array systems in the Western World.

1964 Development started by USAF-Texas Instruments on the MERA phased array. This was the first all solid-state radar program to show the feasibility of the active element concept and to advance solid state technology.

1964 Development by USAF-Bendix on the SPADAT phased array which operates in the UHF frequency range. This is the physically largest phased array with a 50 Megawatt peak power.

1964 HAPDAR phased array was designed by Army-Sperry Rand to demonstrate the feasibility of producing a low cost high performance phased array for simultaneous search, acquisition and multiple target tracking.

1965 RARF phased array was designed by USAF-Raytheon which operated at Ku band and contained about 3800 elements.

1965 Development started on the NOTS phased array by Navy-Raytheon which operates at X-Band. First phased array designed to operate with circular polarization for a main rejection mode.

1967 Navy-Raytheon developed the MAIR phased array at X-band to determine the feasibility of producing a multi-mode airborne array radar.

1969 Development of the RASSR phased array by USAF-Texas Instruments to operate at X-Band with reliability greater than 500 hours MTBF.

1970 First flight test of the RARF phased array demonstrated beam scanning and steering capability.

TABLE 17 AVIONICS - RADOME, BACKGROUND

A CHRONOLOGY OF EVENTS IN THE AREA OF RADOMES

1941 The first radomes constructed of plexi-glass were used on the B-18 airplane in flight tests of the SCR-519 radar.

1941 Radomes constructed of 1/4" thick plywood used on the B-18 airplane in flight tests of the Aircraft Intercept radar.

1941 Thin-wall plywood radomes used on 15 "Night Fighters", P-61's in flight tests of S-band AI radar.

1941 Efforts were made to rectify electrical performance deficiencies encountered in plywood radomes due to moisture absorption by applying a thin overlay of resin-impregnated glass fabric to the outer surface of the plywood, by constructing the radome out of a new polystyrene foam, or by constructing radome out of phenolic resin impregnated cotton fabric.

1942 Plexi-glass radomes were used during flight tests of the SCR-519 radar on test targets off Tarpon Springs.

1942-1944 Military interests in radomes centered in the Radiation

Laboratory, Massachusetts Institute of Technology, Div. 14, Group 54, represented by Mr. E.B. McMillan; the Signal Corps Aircraft Radio Laboratory, Wright-Field, Ohio, represented by Major A.R. John; and the Naval Air Material Center, BuAer, represented by Commander V.H. Soucek.

1942 The nose radomes on the "Dumbo" pathfinder airplanes were either urea-bonded plywood or glass-cloth laminate.

1942 It was determined that it was necessary to keep the radome walls thin with respect to wavelength to keep wall reflections and magnetron frequency pulling to a minimum.

1942 A "polyfiber" radome developed by the Radiation Laboratory, Dow Chemical Corp., and the Virginia Lincoln Company for the Pathfinder Program.

1943 Techniques for use of a new tough, rigid, low density, low refractive index, cellular, resin-impregnated rubber material, "SS expanded hardboard" developed for Army Air Forces.

1943 First attempts to streamline radomes were made by the Navy on the F6F-3N.

1943 A double-wall construction of two concentric thin-wall radome skins air-spaced from one another by approx. 1/4 wavelength, was tried for a time at the suggestion of the Radiation Laboratory.

1943-1944 Electrical design for the "A" sandwich, three-layered radome developed at Radiation Laboratory.

1943 The first radome made of polystyrene fiber was used on the B-24 airplane.

1944 Half-wave, K-Band, polystyrene fiber construction for Radomes developed at Radiation Laboratory.

1944 Resin - impregnated, glass fabric based honeycomb sandwich construction for radomes developed at Wright-Field.

1944 The first streamlined radome was installed on the B-29 aircraft.

1945 Laminated radomes of glass yarn, knitted into contour-formed socks were developed by Bell Telephone Laboratories, Radiation Laboratory, and Andover Kent.

1945 McMillian, Redhoffer and Leaderman published their theories on the "B" sandwich radomes.

1945 Rain erosion of radomes housing the AN/APQ-7 appeared on B-29 bombers operating out of the Marianna Island against the Japanese.

1946 The Army Air Corps radome activity at Wright Field initiated a long range radome R&D program including among other items rain erosion studies by Goodyear.

1948 Neoprene Protective Coating for rain erosion resistance developed by Goodyear for Air Force and has found wide use in civil aircraft.

1948-1949 Low-Dielectric-constant glass fibers for radomes developed by Glass Fibers Incorporated, for Air Force.

1948 Radome Engineering Manual, Navaer 16-45-502 or AMC Manual 80-4 prepared by the Air Force and the Navy Bureau of Aeronautics.

1948 "A" Sandwich Foamed-in-place radomes developed by Air Force for use on the C-54 nose.

1948 The flush fairing of a radome into aircraft loft line was used on the B-45 airplane.

1949 Foamed-in-place, high temperature (400 F) radome developed by Cornell Aeronautical Laboratory for Air Force.

1949-1954 A considerable amount of general radome theoretical research and engineering design criteria developed both by the Air Force and Navy Laboratories.

1949 Work on high temperature ceramic materials for radomes was completed for Navy at Virginia Polytechnic Institute and for the Air Force at Stupakoff Ceramic Company.

1949 Thermally anti-icing technique was used to de-ice the nose radome on the C-45 aircraft.

1952 Ohio State U. Research Foundation for the Air Force developed techniques and equipment for studying near field of radar antennas based upon the microwave optics of radomes.

1952-1960 First land-based space frame, geodesic, radome, 30 to 55 feet in diameter developed at Lincoln Laboratory for Air Defense Command (Air Force) and became CW-396 radome used by FAA for Air Traffic Control (Long Range Radar) at L-Band.

1952-1956 Inflatable land-based rubberized fabric radome, 55-60 feet in diameter, was developed by Air Force (RADC).

1951-1955 Boeing Airplane Co., for the Air Force, developed a precise supersonic streamlined guidance, half-wave thick, solid laminate, radome in an ogival shape with fineness ratio of approx 3.5:1 and designed for use with a radar antenna aperature 19 wavelengths in diameter for use on the Bomarc.

1953 Largest radome, 25 ft. long and 18 ft. wide, used on the RC-121 airplane.

1954-1955 Boresighting error prediction was developed for the monopulse and conical scan cases at the Glen L. Martin Co. and Dalmo - Victor Corporation for Air Force.

1955 Hughes Aircraft Corp., demonstrated on USAF Falcon radome that the measured error characteristic can be corrected to tolerable limits by a systematic insertion of dielectric obstacles at carefully chosen stations on the inside of the radome.

1955 Specification MIL-R-7705A(ASG), "Radomes, General Specification" published.

1955-1960 First land-based metal space frame quasi-RANDOM geometry radome developed at Lincoln Laboratory. First major installation was a 150 foot diameter radome at Haystack Hill. Both plastic and metal space frame radomes used by BMEWS, DEW, and Pine Tree Lines.

1959-1962 Panelized, 60 - foot, land-based sandwich radome developed by Air Force (RADC)/AVCO.

1960 ATC Report No. ARTC-4, "Electrical Test Procedures for Radomes and Radome Materials", 30 July 1960 revision, prepared by Aerospace Industries Association, approved for military use.

1960 The first supersonic radome used on the B-70. This was the first time quartz fiber and silicon resin were used in the design of radomes.

1961 Filament Wound Ceramic techniques for use in Radome construction developed by USAF-Horizons, Inc., Contracts AF33(657)-8370 and AF33(616)-7872.

1962 Attachment techniques for Large Ceramic Radome Structures developed by USAF-Narmco Industries, Contract AF33(616)-8157.

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1963 Electromagnetic Window Design techniques for Hyper-Environments developed by USAF - Ohio State Research Foundation, Contract AF33(616)-7614.

1963 Integrated Antenna-Radome techniques developed by USAF - Ohio State Research Foundation, Contract AF33(616)-7622.

1966 Radome design techniques for reentry vehicles developed by USAF - Georgia Institute of Technology, Contract AF33(657)-11504.

1966 Techniques for high temperature reinforced ceramic radome structures developed by USAF - Brunswick Corp, Contract AF33(657)-11469.

1966 A set of curves by which the pass band frequencies can be predicted for a wide range of dielectric constants and wall thickness to obtain the required radome transmission efficiencies were developed.

1966 "Techniques for Airborne Radome Design" Handbook, AFAL-TR-66-391, published USAF - McGraw Hill Book Company, Contracts AF33(616)-3279 (Volume I) and AF33(657)-11176 (Volume II).

1967 Fabrication Techniques for Lightweight Hyper-Environment E-M Windows developed by USAF - Brunswick Corp, Contract AF33(616)-3025.

1967 Lightweight Broadband Radomes from Slip-Cast Fused Silica developed by USAF - Georgia Institute of Technology, Contract AF33(615)-3445.

1967 NASA built a broadband radome which operated over four frequency ranges. This was used on the nose of W248 aircraft.

1968 Polyurethane Protective coating developed by USAF - Olin Mathieson Chemical Corporation, Contract AF33(615)3633, found to be 5 or 6 times more resistant to rain and sand erosion. Now used extensively by Military and Civil Aviation to increase service life of radomes.

1968 A radome was built for a pressurized feed horn at Ku band on the C-5 aircraft. It was 1 inch cubic and cost $50.00 apiece.

1969 Millimeter Radome Design Techniques developed by USAF - Georgia Institute of Technology, Contracts F33615-C-1243 and F33615-68-C-1193.

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1969 First X-band and Ku band features incorporated in one radome. This radome was used on the C-130 airplane.

1970 Manufacturing Methods for Large High-temperature Sandwich Structures developed by USAF - Whittaker Corp., Contract AF33(615)-3501.

1971 High Strength, Broadband, Lightweight, Silicon Oxide Radome techniques developed by USAF - Georgia Institute of Technology, Contract F33615-67-C-1594.

1971 Inorganic Nose Cone Techniques for Sidelobe Reduction developed by USAF - Georgia Institute of Technology, Contract F33615-70-C-1237.

SECTION III
AVIONICS
CURRENT AND PLANNED R&D EFFORTS

Mission Oriented Research and Development

The Federal Agencies Research and Development Programs are directed toward their assigned areas of responsibility. Within DoD organizations, a significant portion of R&D is purely military mission oriented in which the connection with civil applications is remote. That is not to say that at some time in the future some of the techniques, devices and equipments will not be found appropriate to civil aviation requirements. In fact, in many instances the DoD efforts establish the technology base in terms of techniques, component design, performance reliability and cost for use at a later date by civil aviation.

The National Program in Avionics in Support of Civil Aviation

Federally sponsored or supported research and development programs in avionics has, for many years, provided a major technology base for subsequent commercial avionics development for civil aviation. These government agencies, principally the Department of Defense, Department of Transportation and the National Aeronautics and Space Administration, sustain and support avionics development in many areas which are directly translatable to civil requirements. This is exemplified by the current and projected development programs in the following general areas:

1. Aircraft Navigational Systems. The military-developed inertial navigation systems are now just beginning to be introduced into civil aviation.

2. Flight Control and Stability Systems. Self-adaptive flight controls developed by the military to improve the handling and stability qualities of aircraft are appropriate for the new generations of commercial aircraft now emerging.

3. Air Traffic Control. Under DoD and DoT Programs relating to enroute position locating and reporting, as well as terminal area landing assistance are addressing compatible systems for both military and civil aviation.

4. Communications and Automated Data Systems. The evolution of high capacity, automatic communications and data systems, both voice and digital, are making major strides in providing additional channels for the ever-growing communications traffic problems common to both military and civil aviation. This technology will be highly valuable for the planned Airways Communication Satellites.

5. Large Scale Integrated Solid State Circuits. The many integrated circuit device and component developments to meet the military need have direct application to an exceptionally broad spectrum of civil applications. Airborne digital computers, monitoring, and check out equipments are especially benefited.

6. Flight Safety Systems. Research and development in high resolution landing radar, weather radar, collision avoidance, and turbulence detection under DoT and DoD sponsorship have direct application to civil aviation flight safety.

7. Miniaturization and Ruggedization of Components. This work, carried on at many levels within DoD agencies, has the objective of more compact, lighter weight avionics equipment while providing greater reliability and reduced maintenance is highly beneficial to all aviation.

Collectively, the Federal Programs in support of research and development in the above areas aggregates approximately 100 million dollars for FY-72, and in projection through 1975 the R&D investment will probably increase above that amount per year.

In addition to these general areas, the Federally supported research and development spans virtually all technical areas related to civil aviation requirements, including man-machine interfaces, instruments and displays, individual component improvements, very strong emphasis on reliability and self-test, improved manufacturing technology and many other areas highly significant to the development of civil aviation. It must be noted, however, that "avionics" per se, is evolutionary rather than revolutionary. Consequently DoD in meeting their needs initiates R&D efforts and accomplishes tests to prove the performance and reliability. Research and development must build upon the established state of the art, with the objective of increasing capability, improving performance, extending reliability and flexibility within the framework of systems in-being.

U.S. AIR FORCE

The major part of the current and planned Avionics Programs of the Air Force is concerned with advancing the capability of the operational forces and meeting the critical military needs. Basic technology for these needs is being established by conducting R&D activity in six primary avionic technology areas. These are as follows:

1. Avionics System Technology. To maximize the effectiveness of man-vehicle-avionics combination by developing systems engineering approach to avionics design and development.

2. Aerospace Vehicle Information Systems. To view the total avionics information data in order to achieve better modular, reliable and flexible avionics information systems at lower costs.
3. Aerospace Vehicle Reference Systems. To improve position, velocity, attitude and time of air vehicles, inertial sensors, doppler radar velocity sensors, radio navigation receivers, integration and interface techniques are included.
4. Electro-Optics Technology. To develop and evaluate applications for Electro-Optical Sensors, receptors, displays, windows, fibreoptics, optical data processing, Lasers, detectors, modulators, amplifiers, and effects of transmitting media ex. air turbulence.
5. Microwave and Radar Technology. Efforts will provide phase shifters, microwave power sources, radar signal processing and general array technology.
6. Electronic Device and Integrated Circuit Technology. These include analog, digital and adaptive data handling.

These avionics technology efforts will continue to provide support for improvement of communications, navigation, data handling and radars as used by civil aviation. Air Force R&D objectives with potential for spin-off, commonality, complementary, and/or compatibility in context with civil aviation goals can be found in the AFAL Technical Planning Objectives S-1, -2, -3 and T-1, -2, -3. Related efforts occur in similar technical discipline centers at the Air Force Cambridge Research Laboratories (AFCRL) and at the Rome Air Development Center (RADC) and in the R&D contract work centers of The MITRE Corporation, Lincoln Laboratories and Aerospace Corporation. Analysis and trade-off study efforts, keyed to military scenarios, occur at The RAND Corporation and Analytic Services Inc. (ANSER).

Avionic System Technology

The objective is to maximize the effectiveness of the man-vehicle-avionics combination by developing and using a unified systems engineering approach to AF avionics design and development. This objective embraces a technology which is related to all Air Force missions, requirements and system concepts. It will impact particularly the more complex systems by helping to organize the available technology to solve complex problems in system organization, management and automation. The specific efficient objectives are oriented toward evolving whole avionic systems which produce significant improvements in the Air Force's ability to destroy targets within reasonable cost constraints. Trade-off analyses of penetration, target detection identification and neutralization are aimed at producing avionic systems with higher performance, reliability, maintainability and lower cost of ownership and cost of target neutralization. The approaches involve the use of mathematical modeling and simulation of avionics systems in order to evaluate their mission per-

formance and synthesize improved concepts. This analytical tool will produce sensitivity analyses showing which technology will produce the greatest mission performance improvements. Methods are being pursued to effectively integrate subsystem functions such as all microwave functions and all electro-optical functions, use of an identical signal structure for communication, navigation and identification, and optimization of avionic system performance through optimizing the flow and handling of avionic information. More effective standards, techniques and procedures for integration of avionic systems are being pursued through work in electromagnetic compatibility.

Aerospace Vehicle Information Systems

The objective is to minimize the cost of ownership and maximize the mission effectiveness of Air Force flight vehicles by a unified technical approach to information processing, input-output transitions, and transfer links. This TPO supports all aerospace vehicles (airborne, space and missile), both tactical and strategic, and avionic functions that require avionic information handling for mission accomplishment. These are needed to support all 14 national objectives in the Mission/Function areas. The type of system applications, with near-term emphasis included, are: Remotely Piloted Vehicles (Air-to-Air, Air-to-Ground and Reconnaissance): Survivable Satellite Communications; and, the A-X, B-1 and Lightweight Fighter. The capability needed includes the ability to acquire information from various sources, both internal and external to the aerospace vehicle and to manipulate this information for decision, control and reporting purposes. This involves:

1. The hardware and software to handle a wide range of computations across diverse missions.

2. The integrated presentation and control subsystem which reduces demands on the pilot/operator sensory system by situation-exception techniques.

3. The data bus system which permits common "communication" between the functional aerospace vehicle subsystems.

4. The signal processing which reduces demands on the pilot/operator information processing system by providing only "pertinent" data for his decision-making purposes.

5. The data links which interface with the world external to the vehicle, whether for command, control or coordination.

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The goals are to demonstrate aerospace vehicle information systems that:

allow the automatic operation of the vehicle, at critical junctures in the flight profile, so that a single pilot can perform the mission

make the optimum utilization of all installed sensors and information with the minimum hardware cost

are flexible, have growth potential, can be modified with low cost and have universal application

are critical growth steps toward the development of avionics systems for future versions of aircraft presently in development, as well as higher-order systems for more complex missions

can lead to standardization of a large part of the hardware and software in the next generation of avionics systems

collect and make maximum utilization of the previously developed pieces of information technology

offer a significant step toward a fault tolerant avionics system

<u>Aerospace Vehicle Reference Systems</u>

The objective is to develop the capability to provide reference information (position, velocity, attitude, verticality, acceleration and time) of sufficient accuracy and form to satisfy requirements of military mission profiles of aerospace vehicles. Reference information capabilities will be developed to support Air Force aircraft, missile and spacecraft weapon and cargo delivery, reconnaissance, surveillance and support functions. Specific or functional application is for aircraft weapon delivery, navigation, sensor stabilization and transfer alignment, strategic and tactical missile guidance, and spacecraft precision pointing reference and navigation. Technical approaches include inertial sensors and systems, doppler radar velocity sensors, radio navigation receivers, integration and interface techniques, electro-optical celestial and earth trackers, ballistic missile retargeting and software techniques and gravity models, nuclear hardening of guidance electronics.

<u>Electro-Optics Technology</u>

The objective is to provide an Electro-Optics Technology Base emphasizing optical sources, optical control devices, receptors, displays, and the demonstration concepts of integrating these devices

to avionics applications in the spectral region of 0.2 to 1000 micrometers. Electro-Optics Technology supports detectors, displays and photography universally used by avionics systems. Lasers, IR windows, detectors and displays are used extensively in missile guidance sensors, penetration aids, target designators, identification, search, and ranging. Coherent optics allow for new techniques of performing avionic functions, such as optical data processing, holographic lens, three-dimensional display. Typically, several exploratory development approaches are being pursued to permit an appraisal of competitive techniques such as chemical lasers, semi-conductor lasers, gas lasers, liquid lasers, and optically pumped lasers to determine which will best perform specific Air Force mission functions. Detectors are widely used in avionics systems and must perform over the total spectral region from 0.2 to 1000 micrometers. This imposes difficult material, fabrication, and cooling problems and these must be resolved. For airborne systems, the associated components such as windows having broad band characteristics coupled with high integrity for high speed aircraft and a technique for formatting windows to the aircraft structures are difficult problems that must be solved. Experimentation is required to better understand the degradation of imaging performance due to atmospheric turbulence and the techniques for image reconstruction.

Microwave and Radar Technology

The objective is to identify and provide a radar sensor and microwave technology required to improve the performance of and provide alternative growth paths for avionics functions such as reconnaissance, surveillance, navigation, guidance, fire control, weapon delivery, and data transfer. This will encompass both active and passive approaches in useful portions of the spectrum below 300 GHz and extend in scope from critical devices through equipment feasibility demonstration. Efforts will provide the phase shifters, microwave power sources, radar signal processing and general array technology for the development of a multi-mode phased array forward looking class of radar and will further provide for alternative future choices through the development of distributed array techniques. Linear amplifier efforts will be required for the successful implementation of such systems. Digital doppler processing techniques have proven to be a powerful method for improving the resolution of microwave radar in real time and to extract signals in the presence of ground clutter. Included in the technical approaches are solid state amplifier development, thermionic sources, high data rate components, antenna elements, conformal arrays, target characterization, synthetic aperture techniques, optical processing, millimeter wave techniques and phased array radar.

Electro Device and Integrated Circuit Technology

The objective is to identify operational needs and delineate technical goals, for the development of electronic device and circuits required by advanced avionic systems. These devices and circuits, for

the DC to IR frequency range, and the associated processes and techniques must be consistent with system functional and environmental requirements, and form the foundation for all avionic systems. The degree of success in the 1970s and 1980s in forming increased mission capabilities is totally dependent upon the timely development of highly reliable, cost effective, evolutionary and revolutionary electronic devices, circuits, processes, and related technologies. New advances in LSI and high speed logic circuit techniques are urgently required and directly and intimately related to the operating performance and cost of future airborne and satellite data relay systems; of real time processors for high resolution synthetic aperture radar systems; of data handling portions of secure communication, command and control systems; and of all general and special purpose computers. Linear integrated circuits and advanced signal generation, amplification, control and detection devices directly support the requirements of sophisticated electronic warfare, communication, navigation and reconnaissance systems. Goals are the development and demonstration of: high speed, low power, economical and reliable integrated circuit data handling integrated circuits; a wide variety of high density, low cost, reliable memories such as high read-write speed, non-volatile memories for radar processing and mass memories of 10 gigabit capacity or more for surveillance systems; and a wide range of critical generation amplification and special devices.

The military technology base programs are providing the necessary electronics techniques and components for all the future avionics systems needs of civil aviation. Some of these areas are improvements in avionics systems for air traffic control, computer applications, surveillance, navigation, collision avoidance and terminal area systems. One significant technological contribution is to meet the goals for application of phased array radars to air traffic surveillance.

The previously mentioned major avionics technical activities provide direct support to systems programs such as TRACALS (Air Traffic Control Approach and Landing Systems), PLRACTA (Position Location, Reporting and Control of Tactical Aircraft), and CNI (Communication, Navigation and Identification).

TRACALS (Air Traffic Control Approach and Landing Systems)

TRACALS combines Air Force ground equipment and facilities to provide for the safe and expeditious aerospace vehicle movements on a worldwide basis. It includes terminal and enroute navigation, approach and landing and air traffic control communications. TRACALS will be compatible with the Civil (FAA) System but must provide these capabilities on the battlefield and beyond civil facilities. Though providing systems and equipment unique to its own requirements, TRACALS will make maximum use of other programs.

PLRACTA (Position Location, Reporting and Control of Tactical Aircraft

The primary goal of PLRACTA is to provide a high capacity, secure, jam-resistant information distribution, data processing and display system in the tactical area. It will provide a high capacity data link and an automatic data processing system. The nature of the communications system used will permit vehicle position determination and control. In addition, to its other tactical functions, PLRACTA can supply a large part of the necessary inputs to TRACALS. PLRACTA is funded for 1.6 million dollars in FY-72 and 2.0 million dollars in each of the next two years.

CNI (Communication, Navigation and Identification)

CNI will provide improved communication, navigation and identification through exploitation of recently developed technology. Within the program will be consolidated planning for future systems providing these functions. Unlike PLRACTA, the CNI must be worldwide and will probably make extensive use of satellites. CNI is funded for 0.5 million dollars in FY-72 and 0.5 million dollars in FY-73.

U. S. NAVY

The United States Navy has a large R&D Program that covers many areas. The Navy has, of course, extensive shipboard operations, large programs in antisubmarine warfare, and their aeronautical systems must operate from both land and carriers of various types. As would be expected, a large portion of the R&D effort is directed at non-avionic items, and within the avionics area much effort can be classifed as strictly military, i.e., Electronic Warfare. Certain Navy programs that would appear to have potential civil uses have been identified. These programs have been grouped below under five broad application areas. Tasks within these technology areas, while dedicated to Naval operational needs, also provide major improvements in techniques and components applicable to civil aviation needs.

Communications

The Navy has an extensive program in communications for both short range and global applications. An aircraft HF communications system and satellite communications are the two largest programs. In addition, there are technology developments of various types. These are aimed at improvements to existing systems and new technique development, and include such things as improved digital transmission, VLF techniques, and better components. The FY-72 funding in this general area is estimated to be about 6 million dollars.

Electronic Data Processing

The Navy is expending 1.4 million dollars in FY-72 and about 5.4 million dollars for the next two years. This effort is primarily devoted to hardware cost tradeoff for large data handling systems. In the future, the Navy will support LSI functional circuitry.

Display Technology

The Navy is expending about 1.8 million dollars in FY-72 for basic techniques in advanced command and control multi-function displays. The technology is applicable to civil aviation. For the next two years, about 4.1 million dollars will be expended.

Navigation

The Navy's Exploratory Development Programs in navigation include inertial navigation, radio navigation, and satellite navigation. An extensive effort is being made in the satellite area to develop methods of rapid information readout. All of these techniques can have application to the commercial field. Estimated funding for FY-72 is 5.5 million dollars.

Air Traffic Control (ITACS)

In the area of advanced systems development, the Navy is developing an Integrated Tactical Air Control System (ITACS). This system will provide a shipboard capability for full control of Navy air tactical operations. ITACS will incorporate an Integrated Tactical Navigation System as well as a Multiple Interior Communications System and an Advanced Avionics Digital Computer (AADC).

U. S. ARMY

A portion of the U.S. Army program contributes to civil aviation. These are the joint services TRI-TAC Program and a proposed new Army Integrated Battlefield Control System (IBCS), and the Tactical Landing System. In addition to these, the Army has a program of technology development that will supply basic advances in many areas of electronics. Other Army efforts are directed at weapons and weaponry such as armed helicopters and armored vehicles.

TRI-TAC

TRI-TAC is a tri-service communication system that developed out of the former international MALLARD System. The purpose of TRI-TAC

is to provide a unified tactical communication system for the three services and is to be jointly supported by these services. However, in FY-72 Air Force and Navy funds for their portion of the system were not approved. Development is continuing under Army support. The system will support both voice and data transmission and will serve point-to-point and air-to-ground operations. Although the system itself will have no direct civilian counterpart, the hardware techniques, technical aspects and system techniques should be directly transferable to the civilian market. The Army FY-72 budget for TRI-TAC was 5.2 million dollars.

IBCS (Integrated Battlefield Control System)

The IBCS is a new program which was started in FY-72 by the Army. IBCS is an automatic data transfer system and its main purpose is to tie together various Army battlefield operations centers. This will be largely a computer-to-computer data system. Basic techniques and methodology should find civilian application.

Army's in-house research in guidance for helicopter steep approach resulted in: A-SCAN scanning-beam microwave guidance equipment, developed by AIL for Army as a variable-parameter guidance package for the in-house flight research program and served as the base for the current advanced development of the Tactical Landing System. Army work, and the Army role in National Plan for MLS will be of major benefit to civil V/STCL landing efforts.

Army loaned the experimental A-SCAN equipment to FAA for field experiments in the area of low-cost approach systems for small civil airfields, and also at FAA request supplied and operated the A-SCAN in joint FAA-California State Aeronautical Department demonstrations of operational potentials of V/STOL aircraft in the civil environment.

In addition to programs having specific military application, continuing efforts are being conducted in improvements to communication electronic data processing and displays. These basic technology programs in techniques and components, listed below, have a direct output for application to civil aviation.

As a technological base for investigation of new ideas, concepts and techniques in aviation electronics, one objective is to obtain data and determine the feasibility of applying new aviation electronics technology to Army aircraft and ground based avionics equipment. Particular emphasis is placed on helicopter operations at night and during periods of reduced visibility. These efforts are aimed at achieving a capability to provide airmobility support during weather conditions under which the ground forces operate. Exploratory

development is composed of four projects: 1. Navigation, Positioning, and Landing. 2. Air Traffic Management. 3. Aviation Communications. 4. Airborne Avionics Techniques.

Airborne Avionics Techniques includes investigation of environmental sensing, instrument/displays, and flight control systems. The work performed in these projects is needed in order to establish and maintain a sound technological base for progressing to advanced and engineering development.

Advanced development of aviation electronics equipment and systems to support Army Aviation is focused on the Army helicopters and improving their capability to support ground combat forces. The ability to perform combat and combat support missions, such as medical evacuation and resupply, at night and during adverse weather, is presently limited by avionics and ground based equipment necessary to provide the functions of navigation and air traffic control under tactical conditions. The Automated Air Traffic Management System (ATMS) project is composed of tasks for enroute, approach and departure control and airborne subsystems. Priority for development is given to the Air-Ground Digital Data Link Task, and to the Tactical Landing System tasks in order to provide equipment for military potential testing. A task for the development of an Air Traffic Management System Performance Model is included to allow for system trade-off analysis and optimizing of the system. The Collision Warning System task provides advanced development models of commercial off-the-shelf equipment for evaluation. The Flight Instrument Display task provides for development and evaluation of Flight Directors, Project Map Displays, and other situational information devices; Army, Navy and Air Force are jointly investigating the area under JANAIR (Joint Army-Navy-Air Force Instruments Program) which sponsors study on man-machine interrelationship, human factors, displays and control. The Doppler task provides for the evaluation of new, lightweight and low cost airborne Doppler radars which can be used to augment and improve existing and planned airborne navigation systems.

Aviation electronics systems and equipment to improve the night and adverse weather capability of Army Aviation and to improve support to combat forces result from a continuing need for development and improvement of ground based navigation systems, avionics ground control systems, test equipment, and quick reaction requirements. This program element gives priority for development to a positioning and navigation system employing the LORAN. Engineering development of air traffic control tower equipment and nondirectional radio beacon equipment is included as part of the Positioning and Navigation System (PANS) and Air Traffic Management System (ATMS) development. Engineering development of airborne avionics systems

such as high frequency radios, radar altimeters, and special devices for developmental aircraft systems are included.

Examination of techniques and concepts for avoiding obstacles and objects at day and night and during reduced visibility will continue. Specific areas in which studies and analysis will be conducted are: Lasers, radar, field of view measurements, and display techniques. Flight control studies and simulation of load stabilization and the effects of oscillating loads on the handling qualities of large cargo helicopters will be conducted. In the area of navigation, investigations of navigation computer techniques and hybrid techniques (by radio-inertial) will be conducted. An in-house study addressing the problems of interfacing air traffic management with the tactical environment will be conducted. Emphasis will be placed on providing an understanding of data exchange requirements with Air Defense systems and other services during tactical operations. A detailed study will be initiated to define the man/machine interface requirements for the operation of Army aircraft low level at night and during periods of poor weather. The study consists of simulation, limited flight testing, and investigation of available techniques and technology to accomplish a low level operations capability. Antenna designs to achieve electrically efficient integrated airborne antennas will be formulated using computer techniques.

The helicopter multiple function system (HELMS) is being evaluated by the Army. It uses a precision surveillance radar with the antenna mounted in the leading edge of the helicopter rotor blades, thereby eliminating the need for a dish antenna and radome. The high resolution provided by HELMS will have application and navigation approach to unattended landing zones, weather avoidance and station keeping. The addition of a second antenna slaved to turrets will provide gun and sensor direction capability.

Development is in progress for a collision warning device for Army aircraft for the purpose of enhancing safe conduct of aerial missions in the tactical environment. The system will detect and issue a warning to the pilot whenever an aircraft is on a collision course or on a near miss course with another aircraft equipped with the same system. The warning will be generated at a fixed time prior to collision or near miss and takes differences in aircraft velocities and approach angles into consideration. The device is, in effect a pulse beacon ranging system where each device serves both an interrogation and response function. A collision warning capability has the potential of increasing the effectiveness of Army aviation by allowing conduct of tactical missions with reduced mid-air collision hazards and more efficient use of tactical airspace. The program is coordinated with the FAA program in that field.

Current Army programs will initiate engineering development of the LORAN Manpack Receiver, type-classify the Low Frequency Beacon, AN/TRN-30 and conduct engineering test/service test of a High Frequency Single Sideband (HF-SSB) Airborne Radio Set. The LORAN Airborne Receiver Contract Definition Program involves the flight test of the validation models and by testing models with a simulator, evaluation of the test results, Engr. Dev. proposals and study efforts of the contract definition contractors in preparation for award of a follow-on engineering development contract.

NASA

The National Aeronautics and Space Administration Avionics Program as related to aircraft operation has been small. However, for space systems and their operations, major programs have been undertaken and extensions of these efforts are continuing. These programs have some direct fallout to civil aviation. Previous avionics development for aircraft operation has been conducted in the area of automated flight control systems, data processing and displays. One of the important future NASA programs in avionics is the Computer-Centered Digital Systems for both flight management and advanced control application. Computer-centered systems from the piloting or flight management viewpoint will be essential in performing a number of functions as follows:

CTOL, STOL*

Precise route-time flight profiles
Flight director with path angle and acceleration
Climb and descent envelopes
Noise abatement approaches
Pictorial navigation display
Air Traffic situation data
Status of complex systems

VTOL*

Time critical, complex control during approach
Minimize powered-lift energy
Precision, low-altitude navigation

One of NASA's major programs is the development of STOL avionics. This task involves the preparation of an all-digital guidance and control system in a STOL research aircraft in FY-74; this will provide an effective goal for validation of the new MLS (Microwave Landing System) for STOL application. This program is estimated to cost 9.8 million dollars for five years with 4.0 million dollars for FY-72.**

* NASA SP-292 "Vehicle Technology for Civil Aviation; The Seventies and Beyond." - A Conference Held at Langley Research Center, Hampton, Virginia, November 2-4, 1971. pg 287, "Advanced Avionic Systems" by G. Barry Graves, Jr., Langley Research Center.

** DOT/DOD/NASA National Plan for Development of the Microwave Landing System, July 1971.

DoT/FAA

FAA Electronics R&D is primarily in support of system concept, navigation, communications, air traffic control, data processing and displays. One of the major programs is the ATC (Air Traffic Control) Program. The ATC Program includes all elements of the system required to support air operations from takeoff to touchdown. Electronics developments fall in the broad areas of Data Acquisition, Data Transmission, Data Flow Processing, Navigation and Collision Avoidance. FAA R&D is characterized by system and hardware development rather than by basic electronic technique exploration. Unlike the military, FAA R&D provides a direct output in the form of a service to the civilian (and military) community, its primary goal being the safe and expeditious flow of all air traffic. The total FY-72 R&D budget for ATC is 74.4 million dollars, the larger part of which can be considered electronics. The discussed programs are listed by program name used by FAA.

Satellite Program

U.S. Ground-Based Surveillance Systems do not provide complete coverage of the entire airspace, especially at low altitudes, below the line-of-sight. Position and altitude errors vary depending on the type of surveillance system and the distance from the ground station. A satellite system could replace much of the ground equipment, provide coverage at all altitudes, and provide improved position and altitude information through the entire continental United States. The prime objective of this program is to determine experimentally that such accuracy can be achieved. In addition, the program will determine the practicality of such a system and accumulate data to support a decision on the use of satellites for aircraft surveillance in the continental United States. The current funding for FY-72 is 1.8 million dollars with a planned 60 million dollar effort through 1982.

The need exists to handle on the order of 50,000 aircraft simutaneously over the United States. The Satellite Program described here is one technique leading to the satisfaction of this requirement.

Oceanic Program

Present oceanic traffic control is accomplished without surveillance. This results in wide corridors and large traffic separation with the resulting low capacity of the system. This is caused by lack of accurate position data on-board the vehicle and lack of adequate long range communication. The major objective of this program is to improve oceanic communication through use of communication satellites. The early phase will be used to evaluate technical and operational performances between ground, and aircraft over the ocean. A navigation and surveillance function of the system is covered elsewhere. NASA is also supporting the above satellite systems. The current funding for FY-72 is 1.9 million dollars with a planned 60 million dollar effort through 1982.

Communications Program

The current ATC (Air Traffic Control) communications is exclusively a voice system; VHF-AM for civil traffic and UHF-AM for military traffic. Increased traffic requirements overload the system in data capacity and in the number of available channels. The objective of this program is to develop digital systems to:

Relieve pilots and controllers of workload

Provide rapid, reliable digital communications in support of an automatic ATC system

Provide more effective use of existing frequencies

Provide a flexible system capable of accommodating short and long range system changes.

This program is limited to continental United States operations. Long range communication is covered in the AEROSAT Program. Much of the program is devoted to improvements to existing systems and hardware. An automatic digital air-ground system called DABS (Discrete Address Beacon System) is being developed. This system will provide automatic call-up of a desired aircraft and will provide ATC command to the aircraft and provide automatic position reporting from the aircraft. The schedule calls for prototype specifications in 1974 and operational trials starting in 1977. The current funding effort for FY-72 is 4.6 million dollars with a planned 34 million dollar effort through 1982.

Landing Systems Program

UHF/VHF Instrument Landing Systems are vulnerable to interference from surrounding terrain and structures. This vulnerability limits the growth to provide service at all qualified runways and airports. It further limits the capacity of the terminal area of the near future in which long, straight-in approaches will be replaced by shorter, segmented or curved tracks using three-dimensional guidance inputs to achieve precise arrivals at the runway threshold. Runways and airports requiring the use of V/STOL aircraft cannot be served by current ILS, since it is dependent on large, clear, flat areas for effective antenna radiation. The primary objective of this program is to eliminate the ILS deficiencies by developing and installing a new Microwave Landing System (MLS) that supports all types of aircraft and accommodates any landing rate that the airport requires. In addition, the current ILS is to be improved to achieve improved performance at airports troubled by siting problems. An interim system shall be developed for V/STOL operation. The MLS portion of this program is supported jointly by the DoD, DoT, and NASA. The estimated current funding for FY-72 is 11 million dollars with a planned 106 million dollar effort through 1982.

Collision Avoidance System and Pilot Warning Indicator Program

The primary objective of air traffic control is to provide control to prevent mid-air collisions and near misses. Near misses are reported frequently and mid-air collisions do occur. The Collision Avoidance System is an air-derived, all-weather system that determines the degree of danger as to air-to-air collision, and, if necessary, provides the pilot with an indication of a safe evasive maneuver. The pilot warning indicator is an air-derived system useful under fair weather conditions. It determines when another aircraft is within an area of potential conflict and provides the pilot with some clues as to where he should look. The objective is to determine the compatibility of existing concepts for air traffic control, and identify any design or operational changes needed to achieve compatibility., develope and test ground stations, develope cost, schedules, and locations for deployment of operational ground stations ,and develope low-cost avionics with lesser capability for general aviation. The current funding for FY-72 is 3.4 million dollars with a planned 12 million dollar effort through 1982.

Flow Control Program

En route traffic is currently controlled by a number of ATC Centers. The action of one center can interact with many others, even on the other side of the country. A central flow control facility has been established to coordinate the flow of control data

between centers, however, many administrative and technical problems must be solved. The objective of this program is to provide a facility that can provide the smooth and expeditious flow of air traffic. This will be done primarily through a three-phase software program to help automatic data flow. Technical support is provided by the Transportation System Center (TSC). The current funding for FY-72 is 0.8 million dollars with a planned 6.1 million dollar effort through 1982.

Radar Program

Existing traffic control radars are deficient in the following areas:

detecting targets with zero relative velocity

ground clutter

detecting small aircraft in clutter

"angel clutter" from birds and air convection "bubbles"

Because of the declining role of radar in ATC, FAA has decided against developing new radars. The program will be limited to improving existing equipments. The current funding for FY-72 is 1.6 million dollars with a planned 8.1 million dollar effort through 1982.

DoD SPONSORED AND COMPANY FUNDED IR&D

Industrial Independent Research and Development (IR&D) provides a substantial force for technology advances. Avionics-related efforts are identified among the Electronics and Electrical Engineering (COSATI-9) (Coordination of Scientific and Technical Information) programs of nearly one hundred corporations which have submitted their plans for military review, representing approximately a 200 million dollar effort in FY 72. DoD funds support approximately 50% of avionics industry IR&D efforts. An estimate of 20%-25%, as a factor representing potential relevance to civil aviation, suggests a value of the order of 72-123 million dollars for these R&D objectives. The programs are arranged and presented in terms of the COSATI technical areas, with avionics interests reported primarily in the 09-Electronics and Electrical Engineering. The individual work effort descriptions then can be readily sorted to the technical applications areas used in DoD program analyses. Twelve areas (Communications, Data Processing, Display, Navigation, Sensing and Fuzing, Guidance and Control, Power Sources and Distribution, Target Acquisition and Tracking, Surveillance, Electronic Warfare, Electronic Intelligence (ELINT), and Identification of Friend or Foe (IFF)) can

be reduced to areas of principal complementarity or potential commonality with civil aviation goals by eliminating the major military areas of Electronic Warfare, ELINT & IFF. These are sharply tuned to objectives with visible military relevance, but there are always zones of common aeronautical mission profiles where translations of technology to the civil realm can occur. For example, the Air Traffic Control Radar Beacon System (ATCRBS) currently employed by FAA in the Air Traffic Control System is a direct application of the basic Military MARK X IFF beacon which was developed for a strictly military application.

SECTION IV
AVIONICS
SUMMARY

As the number of airplanes increased and designed to fly faster and farther, the necessity for reliable communications, navigation and control became vital in the performance of the mission and safety of personnel. The application of electronics to aviation was essential and began with the military. This was soon followed by the joint development of the four course low frequency radio range system by the Bureau of Standards and the Signal Corps of the United States Army. These two important aspects in the development of aviation received much attention in the 1930s by both the military and civil aviation communities.

Other than for communications and navigation, little progress was made in avionics until just prior to WW II. At that time, it became evident that the realistic application of the airplane as a military weapon was born and developments in many areas of electronics became an absolute necessity. Among the many developments at that time were radio detection and ranging (RADAR) systems, fire control systems, bombing and guidance systems and an elementary television bomb guidance system. WW II was a turning point. In the late 1940s, many of the wartime (usually classified) developments were released for civil application. These techniques and equipment developments led ultimately to such things as radar for air traffic control and Ground Controlled Approach (GCA), radar beaconry, radar altimeters, doppler navigation, multiple channel communication equipments. The currently used enroute navigation system (VOR), was developed during the war years by the Civil Aeronautics Administration and was accepted as a worldwide standard by the International Civil Aviation Organization (ICAO) in 1946. In 1957 TACAN was added to VOR to form VORTAC which is the present system of navigation.

Inertial navigation is just coming into use by civil airlines in the latest transport aircraft mainly in transoceanic service. These equipments are direct descendants of military equipments and owe their basic technology directly to military research and development. Another development of the past, with still a large future to be explored, is the field of microelectronics and LSI. These techniques, with a large military input, have already found wide application in civil aviation and without them the present large application of computers would not have been possible. Satellite systems have already opened a new world of communication and navigation. Developmental navigation satellites are in operation, and trans-oceanic telephones and live television are a reality. NASA has demonstrated live television from the moon. Greatly increased communication capacity can be provided by the satellite through removal of the usual shortrange line of sight limitation of microwaves, and the atmospheric interruptions of the

normal long range high frequencies are virtually eliminated. Satellites will permit direct communication with aircraft in oceanic flight, provide accurate navigation and therefore will permit safer traffic control with greater capacity. The civil and military space flight programs have played a significant role in revolutionizing avionics and is just beginning to impact the aircraft design.

Current government programs will continue to contribute a large technology base to future developments. New techniques in solid state electronics, particularly in microwave components, and further improvements in LSI will permit smaller, lighter and more reliable longer life hardware, and possibly more important, they will enable introduction of devices for civil aviation not now possible. New techniques will permit capabilities not practical with ordinary solid state construction and not possible with the older vacuum tube technology. Modern digital techniques will permit automatic, more accurate, and more reliable flight control systems, and automatic communication and navigation systems. Phased array antennas will permit more flexibility, mode shifting, higher resolution and other lower life cost radars as well as communication systems. For example, the Microwave Landing System (MLS) to be jointly developed by DoD, NASA and DoT will use all of the above techniques and will provide a more accurate and flexible instrument landing capability leading to automatic landings. This new system will permit installation at many airports where current systems are not now practical and it will be able to accommodate all types of aircraft including V/STOL. Satellites will play an expanded role in the future. These new systems could help to bring modern air transportation to areas and countries not now served.

The largely military sponsored system design and totally integrated system approach techniques are also expected to play a major role in future developments. Such techniques will permit the development of major systems, both aircraft and ground traffic control, on a more logical basis.

The military R&D program is by nature aimed at military problems, however, even much of this such as the safe movement of large numbers of aircraft under controlled conditions, is common to civil aviation. But even the uniquely military developments can find applications to the civilian sector. The military program covers the spectrum of science from basic research to operating systems, and the technology base provided may find application in many fields. Even a bombing system might provide components with unrelated applications. For example, a low light level television sensor might provide night time news coverage of events not now possible.

Military technology avionics contributions to civil aviation have been extensive. The major civil programs such as the Microwave Landing

System will draw on techniques, components and devices developed by the military. These programs will have some military support which is necessary to permit military as well as civilian use. Basic avionics technology largely supported by the military will continue to increase in R&D funds expended. Large common avionic systems programs involved in all types of civil aircraft, the National Airspace systems and satellites will have to be accomplished as a joint venture between the military and civilian agencies.

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ABBREVIATIONS

AAF - Army Air Force
AAC - Army Air Corps
AAS - Army Air Service
ADC - (Air Force) Air Defense Command
ATC - Air Traffic Control
AM - Audio Modulated
A/C - Aircraft
ADVENT - Communications Satellite Name
A-N - Morse Code for Letters "A" and "N"
AI - Aircraft Interception
AILS - Advanced Instrument Landing System
ATCRBS - Air Traffic Control Radar Beacon System
AIMS - An Acronym derived from ATCRBS, IFF Mark XII, Systems
API - Air Position Indicator
AGED - Advisory Group Electron Devices
AFAL - Air Force Avionics Laboratory
ATMS - Air Traffic Management System
BPS - Bits per second
BWEWS - Ballistic Weapon Early Warning System
COSATI - Coordination of Scientific and Technical Information
COMSAT - Communications Satellite
CW - Continuous Wave
CSAR - Communications Satellite Name
CVR - Controlled Visual Rules
CNI - Communication, Navigation and Identification
CTOL - Conventional Take-off and Landing
CARD - Civil Aviation Research and Development
DME - Distance Measuring Equipment
DOD - Department of Defense
DOT - Department of Transportation
DABS - Discrete Address Beacon
DDA - Digital Differential Analyzer
DECCA - DECCA Navigator Company
DIL - Doppler Inertial Loran
DEW - Defense Early Warning
DC - Direct Current
ECOM - Electronics Command
ENIAC - Electronic Numeric Integrator and Calculator
E-M - Electromagnetic
ELINT - Electronic Intelligence
FM - Frequency Modulated
FSK - Frequency shift keying
FAA - Federal Aviation Administration
FM/CW - Frequency Modulated, Continuous Wave

FAS - Federal Aviation Service
FR - Instrument Flight Rules
GCA - Ground Control Approach
GAT - General Aviation Transponder
HF - High Frequency
HAPDAR - Hard Point Demonstration Array Radar
HF-SSB - High Frequency, Single Side Band
INS - Inertial Navigation System
ILS - Instrument Landing System
IFF - Identification Friend or Foe
IC'S - Integrated Circuits
IR - Infra Red
ITACS - Integrated Tactical Air Control System
IBCS - Integrated Battlefield Control System
IR&D - Industrial Independent Research and Development
Ku-Band- 10.9 to 17.25 MHZ Radio Frequency Range
LOTUS - Communications Satellite Name
LORAN - Long Range Navigation
L-Band - 0.390 to 1.55 MHZ Radio Frequency Range
LSI - Large Scale Integration
MHz - Mega Hertz, new term in lieu of "millions cycles per second"
MTBF - Mean Time Between Failures
MLS - Microwave Landing System
MOS - Metal Oxide Semi-Conductor
MAIR - Molecular Airborne Intercept Radar
MERA - Molecular Electronics for Radar Application
NM/HR(CEP) - Nautical Miles/hour Circular Error Probability
NASA - National Aeronautics and Space Administration
NAFEC- Naval Air Facility, El Centro
NAVARHO- Navigation Rho-Theta
NNSS - Navy Navigational Satellite System
NOTS - Naval Ordnance Test Station
PM/CW - Pulse Modulation Continuous Wave
PPI - Pulse Position Indicator
PAR - Precision Approach Radar
PLRACTA- Position Location, Reporting and Control of Tactical Aircraft
PANS - Positioning and Navigation System
RF - Radio Frequency
RVR - Runway Visual Range
RARF - Radome, Antenna and RF Circuitry
RASSR - Reliable Advanced Solid STate Radar
SAFI - Semi Automatic Flight Inspection
SID - Standard Instrument Departure
SIDS - Stellar Inertial Doppler System
SSB - Single Side Band
SYNCOM - Synchronous Communication Satellite
STEER - Communications Satellite Name
SHF - Super High Frequency

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SIF - Selective Identification feature
SLATE - Small Light-Weight Altitude Transmission Equipment
SPADAT - Space Detection and Tracking
SAGE - Semi-Automatic Ground Environment
S-BAND - 1.55 to 5.20 MHZ Radio Frequency Range
STOL - Short Take-off and Landing
TACSATCOM - Tactical Satellite Communications
TACTSAT - Tactical Satellite
TACAN - Tactical Air Navigation
TRANSIT - Communications Satellite Name
TPO - Technical Planning Objective
TRACALS - Air Traffic Control Approach and Landing System
TRI-TAC - Tri-Service Tactical Army Communications
TSC - Transportation System Center
UHF - Ultra High Frequency
UNB - United Nations Beaconry
USAF - United States Air Force
VHF - Very High Frequency
VORTAC - UHF Omnidirectional RANGE TACAN
VOR - VHF Omnidirectional Range
VTOL - Vertical Take-off and Landing
V/STOL - Vertical Short Take-off and Landing
VAR - Very High Frequency Aural Range
WPM - Words per Minute
X-Band - 5.20 to 10.90 MHZ Radio Frequency Range

APPENDIX 4

MATERIALS

JOINT DoD-NASA-DoT
"R&D CONTRIBUTIONS TO AVIATION PROGRESS"
(RADCAP) STUDY

ALBERT OLEVITCH
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AUGUST 1972

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SECTION I

INTRODUCTION

The advent of the jet engine and the ensuing development and requirements of higher performance aircraft (about 1947) can be considered a turning point for materials research and development between 1925 and the present. Before 1947, there were no significant materials barriers barring the achievements of increased aircraft performance. During this early period the Services were engaged in materials programs of a problem solving or product improvement nature.

The jet engine and high performance aircraft imposed demands on materials of increasing use temperatures and structural efficiency. The demand for increasing use temperatures stimulated research and development efforts which still continues today, on materials such as metals, reinforced plastics, lubricants, textiles, elastomers, coatings, etc.

To meet the need for increasing structural efficiency, new alloy compositions and new heat treatments were developed which produced very high strength metals. However, this was done at the sacrifice of ductility and thus the problem of brittle fracture was created. This in turn brought about the advent of fracture mechanics as a design tool.

In the ensuing parts of this Appendix, an attempt is made to look at past history to show the role and impact of materials research and development on military and civilian aviation. In Section II this history is described. Many materials have played a significant role in the progress of aviation. However, for the sake of brevity, only a selected number of the various materials developments are discussed herein.

Section III on planned future programs was prepared using information contained in the documents listed in the Bibliography. However, the section on planned NASA programs on air breathing engine materials was prepared by Mr J. C. Freche of Lewis Research Center, NASA. It should be noted that this Appendix is concerned with a discussion of the impact of DoD materials R&D on aviation. However, some discussion of NASA planned programs is included insofar as these relate to the DoD planned efforts.

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SECTION II

SIGNIFICANT DEVELOPMENTS SINCE 1925

In this section are discussions of some of the major materials developments of the past. Structural and propulsion materials, aluminum, titanium, vacuum melted superalloys, and reinforced plastics (fiberglass and advanced) are discussed. Manufacturing methods (heavy press, numerically controlled machining, etc.) and other aircraft functional materials (windows, hydraulic fluids, integral fuel tank sealants) are also reviewed.

1. Structural Materials

a. Aluminum - Reference 1 was used to secure the historical data presented herein. The material in widest use in the aircraft industry is aluminum. The first application of aluminum in an air vehicle was the Schwarz airship in 1887. The engine of the Wright Brothers Kittyhawk (1903) was made of a one piece aluminum alloy casting. In the U.S. the first non engine application was in aircraft propellers in 1907. Aluminum covers, seats, cowlings, and brackets were commonly used at the start of WW I. The initial aluminum airframe was for a bomber in 1916 designed by L. Brequet. The usage as fuselage and wing skins first was done in 1914 on the Junkers F-13. In 1921 the Engineering Division, McCook Field (now Wright-Patterson AFB) designed the all aluminum structure of the CO-1 observation plane.

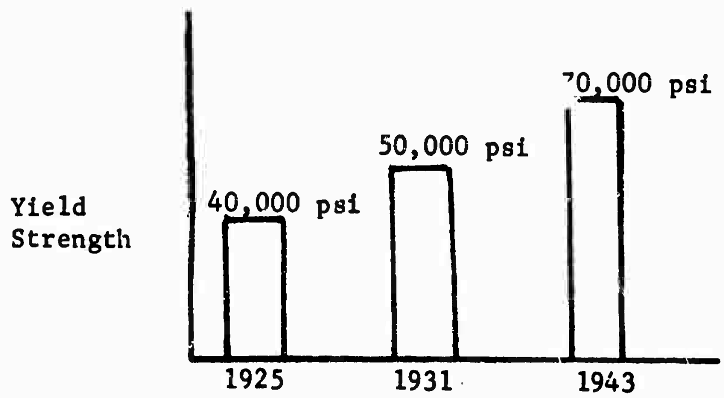
Duraluminum (17S-T or 2014-T4) developed by Germany in the middle 1920's was the first high strength heat treatable aircraft aluminum alloy. In 1931, 2024-T3 alloy with a 25% higher yield strength was developed and subsequently used on the DC-3. Alloy 2014-T6 was the predominant alloy for forgings from 1928-1945. Alloy 7075-T6 with a 75% higher yield strength than 2014-T4 was introduced in 1943. The first aircraft to use this alloy was the Navy P-2V patrol bomber. This is the predominant aircraft structural material in use today.

Alloy 7079-T6 was introduced into this country from Germany in 1954, and in thick sections of 3 inches or greater, it has superior strength and ductility to 7075-T6.

The development of aircraft aluminum alloys technology was accomplished by industry. DoD activity in the way of alloy development was non existent or minimal for many years. With the advent of high performance aircraft, skins were made by machining of thick plate and extrusions. Consequently, the corrosion resistance hitherto afforded by cladding was eliminated. The ensuing corrosion

problems stimulated the need for DoD research and development activities particularly for alloys which had good stress corrosion resistance and fracture toughness. Accordingly, in the sixties, the DoD did participate significantly in development of the X7050 alloy. This alloy has good strength in thick sections, good resistance to stress corrosion cracking and high fracture toughness. It is expected to find wide use in future civil and military aircraft.

In reviewing the past history of aluminum alloy development, the trend had been to develop alloys of increasing strength as shown by the chart below. With the advent of high performance aircraft the emphasis has shifted towards providing better combinations of strength, corrosion resistance and fracture toughness. Emphasis now is on improving the latter characteristics even at the sacrifice of strength and thereby improve the long term characteristics.



b. Titanium - Dr Kroll, in Luxembourg in 1940, published his work on a laboratory method for extracting titanium from ore. By 1948, the Bureau of Mines was able to produce 230 pound batches of titanium sponge using the Kroll process. This achievement by the Bureau of Mines gives substantial impetus to the DoD effort (initiated by the Navy in 1947) on alloy development and fabrication studies. All three Services engaged in a broad and vigorous effort to develop titanium as an engineering material and article of commerce. Over the period 1947-1961, the DoD spent $200,000,000 and established the titanium mill products industry as well as played an important role in alloy development.

The first military aircraft to employ titanium were the XA2J and F86F. The date of doing this cannot be established precisely, but it was done probably in the 1949-1953 time period. According to L. P. Jahnke (Reference 2), subsonic and future supersonic transports would either be economically unattractive or

technically impossible without titanium. Jahnke stated (in oral discussion) that the usage in production engines started in about 1954. Thus using 1948 as an initial starting date, the time required to get into usage was about six to seven years. Considering other materials in general, ten to twelve years is not unusual.

The breakdown of uses for titanium is as follows:

Military Airframes	10%
Commercial Airframes	16%
Helicopter Airframes	1%
Missiles and Space	7%
Military Jet Engines	22%
Commercial Jet Engines	[illegible]
Industrial Uses	9%
Miscellaneous Aerospace	2%

The first military aircraft to use a titanium structure was the B-70 followed by the F-12. North American Aviation on the B-70 and Lockheed on the F-12 developed production methods and know-how on titanium which provided a technology base for the first attempt at using titanium for a commercial aircraft, the Supersonic Transport. This technology was by no means complete or adequate, and as a result the FAA had to undertake programs to develop a much greater amount of design data and to provide a production method for making brazed titanium honeycomb sandwich. This sandwich construction was not involved in the B-70 or F-12 aircraft. Extensive efforts on acquiring design data had to be undertaken because the SST had a much longer operating life. Further, the SST had to be of considerably lower risk than a B-70 or F-12 due to the huge investment and the needs for safety. The FAA invested about 2.6 million dollars in various programs on titanium for the SST.

c. Fiberglass Reinforced Composites

(1) Fiber Finishes - For purposes of this report, composite materials are defined as those in which two or more basic materials are deliberately combined in such a fashion as to maintain each as a discrete structural element acting in concert and providing a unique and useful combination of properties, e.g., glass fibers and plastic resins combined to make a reinforced plastic. The first important application to find operational use was radomes. Radomes are discussed under other sections of this report from the vehicle and electronics technologies standpoint. However, from a materials standpoint, the development of silane finishes for glass fibers ultimately led to reinforced plastic composites which are able to retain their integrity over long periods of time exposed to the humidity of the operating environment. The first plastic radomes

(late 1940's and early 1950's) showed a degradation of about 40% in the original strength due to the continued exposure to moisture. Through DOD sponsored contracts, the development of a new family of finishes called organosilanes, led to composites which lost only 10% of their strength upon continuous exposure to humidity. This development was done under Air Force Contract 33(038)-8902 for $100,000 over the period 1950-1953. Air Force Technical Report 6220, Sept 1951 and Supplements 1 (1951) and 2 (1953) thereto, document this work. Specification MIL-F-9118, Finishes for Glass Fabric, was also issued as a result of this work.

The development of the organosilane finishes not only led to much better performing radomes but also increased the interest and confidence of aircraft manufacturers in expanding the use of composites to fairings, wing tips, aerodynamic surfaces, and ultimately to the present day reinforced plastic structural components. The Boeing 747 uses about 18,000 square feet of reinforced plastic per airplane. The organosilane finishes made the expanded uses of reinforced plastics on this and other aircraft possible. These finishes play a key role also in advanced composites which are the aircraft structural materials of the future as discussed later.

(2) Coatings for prevention of rain erosion - Aircraft must operate in all kinds of weather including flying through rain. Rain drops impacting at high speeds upon plastic and metals have devastating effects. A reinforced plastic can be literally torn to shreds in thirty to forty-five seconds. Aluminum air foil surfaces can be severely dented and eroded. When reinforced plastic radomes were first employed the devastating effects of rain were soon experienced and led to the development of neoprene rain erosion coatings and to continuing research to find better, longer life coatings to resist rain. Higher speed flight has increased the problem. DoD research has recently produced a polyurethane coating which is markedly superior in the ability to resist rain for long periods of time. The polyurethane coating was developed under Air Force Contracts 33(615)-3633 for $163,310 and F33615-68-C-1068 for $124,880 over the period Feb 1966-Aug 1969 and in simulated rain tests lasts three times longer than the original neoprene coatings. Eastern Airlines has coated the radomes on all of their aircraft with this polyurethane coating.

d. Advanced Composites - Advanced composites are materials which are comprised of high strength,high stiffness (for example, boron and graphite) fibers dispersed in plastic resin and metal matrices. The exceptionally high strength and stiffness to weight achieved with these materials greatly exceed that possessed by the traditionally used metals and fiberglass reinforced plastics. These composites portend significant weight reductions in airframes and

engines and undoubtedly will enter into use in commercial aircraft in the future. NASA predicts this will start in about 1980.

The initial effort starting the advanced composites program was Contract AF33(616)-8017 for $60,000 with Texaco Research. This work started on 15 March 1961 and produced the first quantities of boron filament. Because of the high potential of this fiber for reinforced composites, this program was expanded to a total of $180,000. This Texaco program has been followed by numerous contracts accomplished under an Advanced Development Program, ADO-52. The scope of this effort includes development of boron and graphite fibers, developing design data and handbooks on composites, building and testing full size hardware such as helicopter rotor blades, engine hardware, aircraft horizontal stabilizers, aircraft wings, fiber and tape production.

The following is a listing of some of the important contractual efforts:

AF33(616)-8067 - Texaco, $60,000/yr - started 16 March 1961. First contract effort; resulted in small quantities of boron filament which had recognized outstanding potential as reinforcement for composites. Interest by Project Forecast Panel resulted in expansion of contract to $180,000.

AF33(615)-1053 and AF33(615)-3212 - Texaco, $3,000,000, 1963-1966. Development of new and improved deposition processes for boron filament; evaluation of composites.

AF33(657)-12733 - Texaco, $800,000/1965. Operation of filament formation units for supply of filament to composites ADP.

AF33(615)-5275 - Boeing/Vertol, $3,092,000/1966-1970. Development, fabrication and test of CH47 helicopter rotor blades of advanced composite materials.

AF33(615)-2150 - Whittaker, $1,600,000/1965-1968. Development of prepreg tape, fabrication processes and composite data.

AF33(615)-5257 - General Dynamics, $3,474,000/1966-1970. Design, fabrication and test of F-111 horizontal stabilators from boron composite material.

AF33(615)- - Grumman, $2,440,000/1968-1970. Development and demonstration of boron composite wing

structure.

AF33(615)-1445 - North American Rockwell, $2,400,000/ 1969-1970. Design and fabrication of boron composite wing skins for F-100 aircraft.

AF33(615)-1490 - Northrop, $3,000,000/1969-1971. Design, fabrication and test of F-5 aircraft components using graphite fiber composites.

To date, under the Advanced Development Program, the Air Force has spent $67,099,000. The Navy and the Army also have entered into programs to exploit advanced composites. The Manufacturing Technology Division of the Air Force Materials Laboratory has initiated a number of programs ($7,000,000 approximately) to develop production methods. A substantial amount of work under Independent Research and Development (IR&D) funding also is being conducted by the aerospace companies. At its peak (about 1967) the IR&D was estimated to be at about $8,000,000. Currently the IR&D level is roughly about $4,000,000 per year.

It is expected that advanced composites will find increasing use in production military aircraft in the near future (1975). The F-14 is the first production military aircraft to employ advanced composites, in this case a boron-epoxy horizontal stabilizer. After the first contract on boron filament in 1961, ten years of effort was required before the first usage on a production aircraft took place. The F-15 will use boron-epoxy composites in the rudder and stabilizer areas. For the B-1, it is planned to employ a boron-epoxy stiffener bonded to a metal longitudinal beam. Strong future candidates will be STOL and VTOL aircraft where weight reductions are of high payoff. Another application of much promise is helicopter rotor blades. The high stiffness of these materials will allow the use of larger diameter rotors and thus achieve helicopters with greater lifting capacity. Conventional metal blades droop several feet whereby boron-epoxy blades of the same size droop only several inches. Boron-epoxy blades have been shown to have outstanding fatigue resistance. For example, prototype boron-epoxy rotor blades have been subjected to twenty million loading cycles (7,000,000 cycles was the design target) at up to 200% of design loads without failure. The F-111 horizontal stabilizer now in service testing weighs 27% less than the aluminum stabilizer. Rudders of boron-epoxy composite are being service tested on about forty (40) F-4 aircraft.

This new materials technology is expected to come into use in civilian aircraft production in the future. Reference 3 projects that by 1981 civil aircraft structures will be made of 50%

composites and 50% metal alloys. If so, using 1961 as the initial date of work, it will have taken 20 years for composites to have gone into use to any significant degree in civilian aircraft. The use of composites is expected to result in at least a 20% reduction in total vehicle structural weight and in some cases the reduction will be higher. The aerospace companies are today acquiring the experience and manufacturing know-how through DoD and NASA programs. As experience and cost reductions come about through the use on military aircraft, advanced metal and non metal composites will come increasingly into play on civilian aircraft.

e. Adhesive Bonding and Honeycomb Sandwich Construction - Work on the development of adhesives suitable for use in assembling aircraft structures was begun in March 1941, when the Air Force initiated a program to expedite and assist in the development of the Chrysler Corporation's Cycle-Weld process, which showed premise as a method of assembling aircraft with cement, rather than with rivets, spotwelds, bolts, or any other method employed theretofore.

During the period, March through October 1941, the Air Force tested adhesively bonded specimens and Chrysler Corporation improved the adhesives in line with the findings of the Air Force tests. In October 1941, per mutual agreement between Chrysler and the Air Force, Goodyear Tire and Rubber Co. and Goodyear Aircraft Corporation entered into the further development and application of the Cycle Weld adhesives and processes towards fabrication of hardware components. Testing and adhesive improvement efforts were continued which culminated with the development in November 1941 by Chrysler of Cycle Weld C-3 adhesive. A contract was then initiated with Chrysler for fabrication of ten B-26 flaps assembled by adhesive bonding with Cycle Weld adhesive. Contracts were let with Dow Chemical Co. for fabrication of ten P-40 fins assembled with adhesives, and contracts for development and testing of improved adhesives were also initiated.

By August of 1942, a number of parts of aircraft were being made using adhesive bonding. These included B-26 floor sections, flaps for the P40M, and main landing skid mounts for the CG-4 glider. Efforts to improve and further apply adhesive bonding continued. In 1944, brake linings were bonded to brake shoes and bomb bay truss tubes for the B-36 were adhesive bonded in production. AAF Specs 20032 and 20034 for bonding metal to wood and metal to metal were issued in 1944.

The adhesives of the 1940's were limited to use temperatures of about 180°F. In 1951, a program to develop adhesives for use at higher temperatures was initiated and this work continued through 1954 under Contract AF33(600)-6514 with a total expenditure

of $200,000. This work led to the development of epoxy phenolic adhesives for use up to 350°F. This development was the forerunner of the large family of epoxy and modified epoxies which are the basis of adhesive bonding today. Adhesive bonding is finding increasing use in civil and military aircraft. The DC-8, Boeing 727 and 747 employ it extensively. The Yankee, a light aircraft, made by American Aviation Corporation, Cleveland, Ohio uses adhesive bonding exclusively; riveting is totally eliminated.

f. The Air Force Heavy Press Program - Modern commercial aircraft transportation utilizing gas turbine jet engine propulsion would not be available today if it were not for the Air Force Heavy Press Program. The establishment of the program resulted from the need for development of larger capacity facilities to meet the requirement for stronger structural members of airframes and a more efficient method of production of numerous components for both airframes and engines. High speed, high performance aircraft require the greatest structural strength possible with minimum weight. Utilization of new forging and extrusion presses has enabled the production of high strength to weight ratio structural members, quantity production and lower costs not possible by other production methods.

The Heavy Press Program was initiated in 1951 in the form of a heavy press construction program. Participants included Ladish, Wyman-Gordon, Taylor Forge, Alcoa, Dow, Kaiser Aluminum, Curtiss-Wright and Harvey Aluminum. At that time, the 18,000 ton forging press and several 5500 ton extrusion presses were the largest forging and extrusion presses available in the United States. This program provided four new forging presses in sizes up to 50,000 tons and seven new extrusion presses with capacities up to 14,000 tons.

A 12,000 ton extrusion press was installed at Curtiss-Wright originally with the intent of producing steel and titanium propeller blades. Otherwise, the heavy press equipment was planned mainly to provide an industry capability for producing large, integrally-stiffened aircraft structures of aluminum and magnesium alloys. The trend toward high strength, high temperature alloys such as the titanium alloys, superalloys and high strength steels made these presses invaluable as the only way to produce large plan area components of these materials without which modern commercial planes would not be possible. The cost of the Heavy Press Program is estimated at a minimum of $400,000,000. These large presses are owned by the Government. The participants pay for the use of the heavy presses for manufacture of parts for commercial aircraft through lease agreements. The following table describes some vital statistics of the Heavy Press Program.

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VITAL STATISTICS OF HEAVY PRESS PROGRAM

COMMERCIAL APPLICATION	MATERIAL AND/ OR PROCESS	COMPONENT APPLICATION	AIR FORCE PROGRAM	CONTRACT #	FUNDING $	DATE
747	Vacuum Arc Melted Maraging Steel	Fasteners	Mfg process for high strength steels	AF33(657)-11277	$900,000	1966
747	9Ni-4Co Steel	Engine Mounts	Mfg process for high strength steels	AF33(657)-11277	$900,000	1966
CF6 Engine DC-10	Ti-6Al-4V	Fan Blades and Fan and Compressor Disks	Heavy Press Program - 35K and 50K presses		$400,000,000*	1951-1958
			ALSO.......	F33615-68-C-1226	$200,000	1968
			(Overall Ti Technology Programs)		$6,000,000	1957-1968
747	Ti-6Al-4V	Main Landing Gear Beam	Heavy Press Program	F33615-68-C-1226	$400,000,000*	1951-1958
747	Ti-6Al-4V	Flap Tracks	Heavy Press Program		$400,000,000*	1951-1958
JT8 engines JT3 " JT12 " JT4 " JTF10 " JT12 " CJ805 "	Large compressor and turbine disks of superalloys & titanium alloys	For engines in commercial planes 707, 720, 707-120, 707-120B, DC8, DC9, Caravelle, Convair 880 and 890	Heavy Press Program		$400,000,000*	1951-1958

*NOTE: A number of items shown here were done under the $400,000,000 Heavy Press Program. All such references refer to this one program.

g. Numerically Controlled Machining - Numerically controlled machining is used in 70% of the milling metal removal done in the aircraft factory. Manufacturing technology programs of the DoD have created this capability in industry. Quoting from the CARD Study, Vol 1 (Appendix A31), "Numerical milling machines can fabricate fully integrated structural members that would not be feasible if the machines were controlled by human beings. For example, large, solid pieces can be cast and subsequently machined for areas such as the variable-sweep-wing pivot, the landing gear, and the main-wing beams. Since there are no joints in these pieces, weight is substantially reduced by eliminating stress concentrations. Another important feature of numerical milling is that structural design can be directly translated from the computer into the fabricating machine area, thus eliminating templates or extensive mechanical drafting by hand. Other significant advances have occurred in the areas of vacuum welding, brazing, and chemical milling." Significant data on the important contracts on numerically controlled machining are as follows:

Contract No. AF33(038)-24007
Amount: $1,110,000
Project Title: Numerically Controlled Milling Machine
Date of Performance: Feb 1951 through Jan 1960
Project Description: Established a numerical control system for operating a three axis milling machine from information punched in a paper tape. The Automatically Programmed Tool - (APT) data processing system to provide a numerical control program tape was established and demonstrated. Also, a version of APT II was established for use by industry on the IBM 704 computer.
Benefits: Established the numerical control machine tool and computer program for programming of the numerical control systems. Today, the techniques established by this program are being used on 70% of the milling metal removal processes in the aircraft industry as well as in other industries resulting in savings of hundreds of thousands of dollars per year.

Contract No. AF33(600)-43365
Amount: $68,552.47
Project Title: ADAPT - A System for the Automatic Programming of Numerically Controlled Machine Tools on Small Computers
Date of Performance: June 1961 through July 1963
Project Description: The ADAPT system is an automatic programming system for numerically controlled machine tools. Its language is compatible with APT language. ADAPT has commands for tool movement in a two

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dimensional geometric plane.
Benefits; Allowed numerical control programming to be performed on small computer systems. This permitted part geometries of two dimension to be programmed without using the more powerful APT system which has three dimension capabilities and requires a larger computer system. ADAPT is extensively used in the manufacture of aircraft parts which have point to point operations and two dimensional contouring requirements.

Contract No. AF33(657)-10954
Amount: $1,459,000
Project Title: Integration of Design into Numerical Control (CAD)
Date of Performance: June 1963 through October 1968
Project Description: Established effective techniques and media for a man-machine system for (CAD) Computer Aided Design which provides for integrating design information into numerically controlled manufacturing operations. The CAD system enables two way communications between the designer and the digital computer via cathode ray tube light pen techniques.
Benefits: The CAD system allows for a simplification of the process link between the designer and the numerically controlled manufacturing process. This simplification eliminates detail drawings and allows rapid turn around time between designs and design changes and the APT programmed numberical control manufacturing process.

h. Chemical Milling - Chemical milling is a process in which metal is removed by controlled chemical attack of specific areas on a piece of metal. The high performance modern aircraft require minimum weight structure. With chemical milling it is possible to sculpture skins and parts leaving thick areas only where needed. These complex shaped parts could be made by use of conventional machining or metal removal methods but only slowly and at great cost. Chemical milling was invented by North American Aviation in the early 1950's and the technology exploited and improved on military aircraft and missiles. The B-70 stainless steel wing skins were shaped by chemical milling. The Titan II missile case was made using chemical milling. It now is widely used in the fabrication of commercial transports as well as for military aircraft.

i. Design Data (MIL-HDBK-5, Design Allowables for Aerospace Metals) - Originally designated as ANC-5, "Strength of Metal Aircraft Elements", this handbook has, for many years, been the basis for prescription of strength properties permitted in the design of all aircraft. It is now a military handbook, MIL-HDBK-5, "Metallic Materials

and Elements for Aerospace Vehicle Structures". The handbook originated in the 1930's, jointly sponsored by the Army Air Corps, the Navy Bureau of Aeronautics and the Civil Aeronautics Agency (now the FAA, Dept of Transportation).

In the early 1950's, the parent organization of the Army/Navy Spec Group (AN-C-) was abolished. Subsequently the handbooks were converted to the Military series, with FAA participation in MIL-HDBK-5. The Air Force Materials Laboratory was assigned DoD responsibility for the continuing maintenance of MIL-HDBK-5.

Because of the increasing numbers of new materials, data needed, and emphasis on reliability, the demand for a bigger and better MIL-HDBK-5 caused it to grow from less than 100 pages to more than 1000 pages today. This demand included a need for more statistical analysis to assure precise design allowables, which in turn, resulted in a need for assignment of more resources to the handbook. Additionally, NASA has generally contractually required the use of MIL-HDBK-5 for design of boosters and space vehicles.

Because of the need for increasing resources, in 1953 the AFML obtained contract support from Battelle Institute, Columbus, Ohio. This support has been retained continuously since that time, starting at $30,000 per year, then increasing to $60,00-$65,000 per year, and presently operating at approximately $150,000 per year. The current contract number is F33615-71-C-1381. Total funds expended have reached about $900,000 to $1,000,000 solely for the handbook analysis effort.

Although, as noted previously, FAA is a co-sponsor of MIL-HDBK-5, their participation in the past has been primarily that of review and adoption, rather than active sponsorship. Recently the FAA reliance on the handbook has increased to the point where they now provide (for the last 2 years) $35,000 a year support to the Battelle contract. Also the FAA did spend about $145,000 under their SST program to prepare a titanium design data handbook. Some of this data will be incorporated into the MIL-HDBK-5 handbook.

j. Nondestructive Inspection - In 1926 the Materials Branch at McCook Field reported the use of X-ray for determining internal defects in cast and wrought metals. X-ray was also investigated for inspecting welded joints and to inspect aluminum billets intended for forging of propeller blades. Until this event, inspection was done visually using magnifying glasses. In 1927-1929, an alkaline etching procedure was developed for determining defects in aluminum forging. This method became the standard inspection method for aircraft propellers.

These aforementioned activities were the initial pioneering efforts which led to the establishment by the DoD of many nondestructive inspection procedures now used in the manufacture and maintenance of civilian and military aircraft. The work of the DoD in nondestructive testing was recently recognized in the form of awarding the Gold Medal of the American Society of NonDestructive Testing to an Air Force employee. This is the only award made by this Society.

Magnetic particle inspection was first applied to aircraft parts starting in 1930 and perfected by 1933. This method was demonstrated in 1933 by the Materials Branch of McCook Field to the Department of Commerce and the Navy Bureau of Aeronautics and in 1935 complete specifications for magnetic particle inspection apparatus were published. In 1937 this method was adopted by automotive, marine and railroad industries. Today magnetic particle inspection is probably the most widely used nondestructive inspection method for ferrous metal parts throughout all of industry.

Penetrants - Penetrants were invented by Taber DeForest of Magnaflux and R.C. Sweitzer. However, the application of this NDT method was fully developed under work done by the Army and Navy Air Forces in 1942. Demonstrations of its use were successful and employed for use in inspecting hard faced exhaust valves on engines, propellers, engine cylinder heads and crank cases, and other uses.

Ultrasonics - The use of ultrasonics as a nondestructive test technique is well established in the aircraft industry. The history of its development as a nondestructive test technique shows that the DoD played an important role. For example, the present ASTM (American Society for Testing Materials) ultrasonic reference standards are used internationally. These standards were developed from work started in early 1956 by the Air Force. This work is described in reports, WADC TR-57-268 and WADC TR-59-466.

2. Propulsion Materials

a. Titanium - In the discussion of titanium under the section, Structural Materials, the major role of titanium in engines is presented as well as airframes.

b. Vacuum Melting of Superalloys - The importance of titanium to the jet engine was previously mentioned in the discussion of titanium. The other key materials effort which was instrumental in the development of today's jet engines was the development of vacuum melted superalloys. On 23 October 1950, Supplemental Agreement #1 to Contract AF33(038)-1937 was issued to the Utica Drop Forge & Tool Corporation. This resulted in the first production furnaces

for vacuum melting of superalloys (3 furnaces with 6, 50, and 100 pounds capacities) at a cost of $172,000. In 1952 these furnaces were put into operation and produced superalloys not only with more consistent properties but increased the properties by 500%. These results were so remarkable that Pratt & Whitney immediately placed orders which exceeded the production capacities of these three furnaces. Supplement IX, 17 February 1953 to AF33(038)-1937 for $674,000 was issued and two furnaces each with 1000 pounds capacity were installed and operated starting in 1954. These furnaces first provided the forged buckets for the J-65 and/or J-67 engines and also the J-43 engines. With these furnaces it was also possible to reuse scrap from the nickel and cobalt alloys. It can be undeniably stated that this DoD effort also was a key factor in making today's jet engines possible. The impact of vacuum melting on performance of superalloys can be determined from the following chart on bucket alloys.

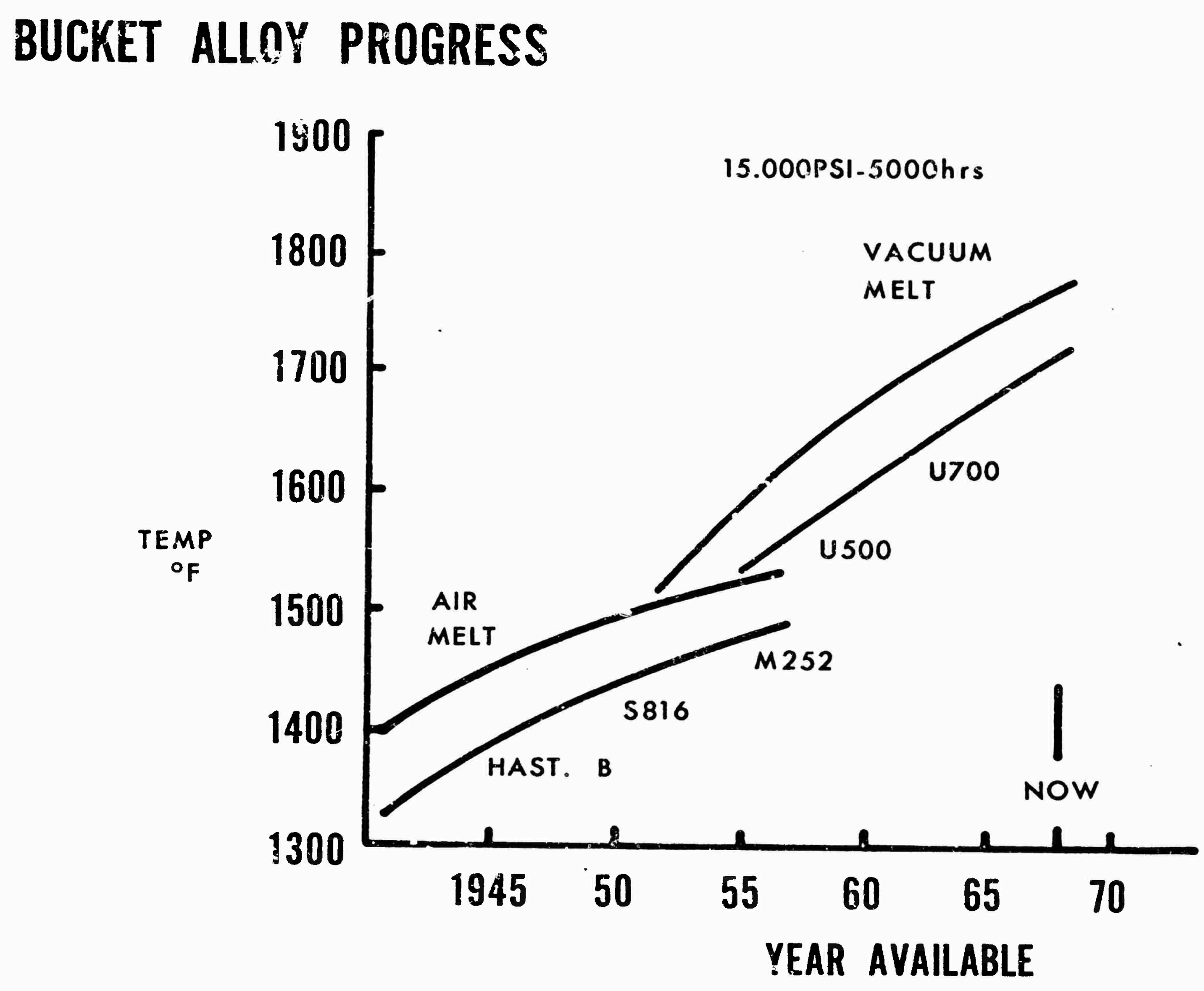
3. Other Aircraft Functional Components

a. Aircraft Windows - The DoD pioneered the development and production of the acrylic plastic windows used today in military and civilian aircraft. According to "Five Decades of Materials Progress" by J. J. Niehaus (Ref 4), in 1937 the Air Force showed that an acrylic plastic, methyl methacrylate (a current brand name is Plexiglass) had greater visibility and impact resistance than non shatterable glass windows and windshields. Tests at Chapman Field, Florida showed that methyl methacrylate was far superior in sunlight resistance to celluloid or cellulose acetates.

In an effort to further improve the impact and crazing resistance of transparent acrylics, on 22 February 1937, the Air Force contracted Rohm & Haas (Contract AF33(616)-489) to develop a process and equipment for multi and/or biaxially stretching acrylics. This effort was instrumental in developing and producing the stretched acrylic windows and windshields used in today's military and civilian aircraft.

b. Aircraft Hydraulic Fluid - The petroleum based hydraulic fluid, MIL-H-5606 (popularly known as "red oil") currently utilized in most military aircraft, and in all commercial aircraft until 1960, was developed and the Specification, MIL-H-5606, written and improved from 1941 through 1960 under Air Force and Navy contracts with Pennsylvania State University. In 1941 a multiplicity of hydraulic fluids of questionable and varying quality existed for all aircraft use. In the interest of simplified logistics and the anticipated demands of military aircraft, a concerted effort was expended to replace the former 24 fluids with one serviceable and reliable fluid. Efforts were directed toward improving the quality

FIGURE 1



BUCKET ALLOY PROGRESS
15.000PSI-5000hrs
VACUUM
MELT
AIR
MELT
TEMP
°F
1900
1800
1700
1600
1500
1400
1300
U700
U500
M252
S816
HAST. B
NOW
1945
50
55
60
65
70
YEAR AVAILABLE

of the base oil by being more selective of the crude source and developing an acid treatment in the refining operation to yield a more stable white mineral base stock from the light oil cut. Further development resulted in an additive compounded fluid with greater oxidative and corrosion stability necessitated by the longer service life being accrued in aircraft systems. Greater anti-wear toward metal parts resulted from further research and the adoption of tricresyl phosphate additive and these developments were covered by Specification ANVV-0-366 and its revisions. The demands of high performance aircraft of Korean War vintage spurred development in 1950-1951 which brought about further improvement in base stock stability by employing better refining techniques, fluid cleanliness of "missile quality" in controlling the number and size of particulate matter, and higher shear stability requirements. Research efforts produced polymers which were shear stable in the modern close tolerance power transmission systems. In this latter era, MIL-H-5606 specification was written to control and continue the aforementioned hydraulic fluid improvements. This fluid is currently used in some civilian general aviation aircraft, in missiles, satellites, spacecraft and all types of associated ground support systems. Most commercial airliners today have switched to a less flammable hydraulic fluid developed by industry.

CHRONOLOGY OF CONTRACTS ON DEVELOPMENT OF HYDRAULIC FLUIDS

Years	Contract
1941-1945	National Defense Research Committee No. OE Mar. 408, \$300,000
1945-1951	Navy, N Ord 7958(B) \$480,000
1951-1955	AF33(038)-18193 \$320,000
1955-1957	AF33(616)-2851 \$180,000
1958-1960	AF33(616)-5460 \$200,000
1961-1962	AF33(616)-7590 \$100,000
1963-1966	AF33(657)-10374 \$360,000

CHRONOLOGY OF CONTRACTS ON DEVELOPMENT OF HYDRAULIC FLUIDS
(CONT'D)

Years	Contract
1966-1969	AF33(615)-3379 $360,000
1969-1972	AF33615-69-C-1183 $375,000

c. Integral Tank Sealing - The following information is based on conversation with Mr Walter Thompson of Products Research Corporation. About 1937, Convair designed the PBY patrol bomber for the Navy which employed integral tanks. Sealing was accomplished with neoprene tape in faying (or abutting) surfaces. In the C-54 the early production (about 1941) used a chromate paste. However, the sealant was switched to the two-part polysulfide developed by Industry (Thiokol) which was and still is the sealant used in aircraft integral tanks. The first commercial aircraft to use integral tanks was the Lockheed Lodestar Model 18 (about 1941). Today all commercial transport aircraft and most military aircraft employ integral tank sealing. This concept eliminated the use of rubber bladder cells and, as a result, saved a great deal of weight.

d. Magnetic Materials for Electronic and Electrical Equipment - In 1966, the DoD measured and reported that yttrium cobalt (YCo_5) had outstanding magnetic characteristics and described a fabrication method for making permanent magnets from a family of rare earths and transition metals (a family of RCo_5 where R is yttrium, cerium, samarium or proecodymium). DoD continued this work to carry out full development including manufacturing methods of samarium cobalt ($SmCo_5$). The following comparison of $SmCo_5$ to platinum cobalt illustrates that magnets of double the magnetic performance, of one-half the weight, and one-fourth the cost, can be made and used. These new magnets have been used in a Hughes 641H traveling wave tube on a prototype basis. The tube performance has improved as follows: 10% increase in power output, duty cycle doubled, 50% decrease in magnet stack diameter, 25% decrease in tube weight. This work was done under Contract F33615-70-C-1098 and F33615-70-C-1097 ($199,000). The original work was initiated in 1959 and was first put into use in traveling wave tubes in 1971, a twelve year span. Further research and development on these materials is continuing.

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SECTION III

CURRENT AND PLANNED R&D EFFORTS

1. Department of Defense Structural Materials Program

a. General - The DoD structural materials program is directed towards materials for use in aircraft which improve performance of aircraft, improve reliability and durability, and reduce costs of manufacture, operation and maintenance. New and improved materials are developed, characterized, and tested for applications to meet future aircraft requirements. Emphasis is placed on providing materials with higher strength and stiffness to weight, increased toughness, higher operating temperature capability, increased stress corrosion and fatigue resistance. Inspectability, fabricability, and processability are also areas of concern in which work is accomplished.

b. Metal Alloys - Materials for structural elements and load bearing skins with assured reliability over a temperature range of 200-1500°F for at least 4000 hours for military aircraft are required. Specific, desired materials capabilities include the following:

(1) Titanium Alloys - High strength (formable by forging and extrusion) titanium alloys with a yield strength of 200-250,000 psi, and fracture toughness (K_{IC}) of 90,000 psi inches and stress corrosion cracking threshold value ($K_{I\ s.c.c.}$) of 69,000 psi inches. These alloys should have sufficient thermal stability such that the ambient temperature yield strength toughness and stress corrosion resistance degrades less than 2 and 5% respectively, at 650°F for 1000 hours at a stress level of 25,000 psi.

(2) Aluminum Alloys - Improved, high strength aluminum alloys will be developed. Further work is planned to provide the newly developed 7049 alloy in production. Target properties are: 85,000 psi yield strength, short transverse stress corrosion resistance threshold values of 40,000 psi in plate and forgings, plane strain fracture toughness (K_{IC}) of 50,000 psi inches for low temperature (200°F) fuselage and wing skin applications. Materials performance is directed towards 30,000 to 40,000 hours aircraft life.

(3) Processing techniques will be developed with emphasis on reducing costs of manufacture and securing structural characteristics comparable with those secured in the laboratory. Powder metallurgy which produces components in final form with minimal machining will receive particular attention.

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c. Advanced Composites - A planning study conducted jointly by DoD, NASA, FAA and the aircraft industry was completed recently and the results published in a report, Composites Recast, of 20 Feb 1972 (Reference 5). This study identified the programs required to translate the use of advanced composites into production aircraft and achieved full coordination of the advanced composites programs of DoD and NASA. This study reaffirmed that the use of advanced composites would reduce aircraft weight as much as 20%, reduce direct operating costs, and increase return on investment. For a STOL system the % reduction in baseline direct operating costs ranged from 9 to 11%. NASA studies show, for an Advanced Technology Transport, that the use of advanced composites can produce a 20% increase in return on investment. Reference 5 identified programs required to make composites an established material of aircraft construction. Some of these are described as follows.

Processing improvements will be accomplished to reduce the cost of boron and graphite reinforcements for advanced composites down from the present \$100-\$200/lb level to \$50/lb for boron epoxy and from \$100/lb down to \$25/lb for graphite-epoxy. Automated fabrication techniques, faster curing systems also will be developed to reduce manufacturing costs.

New polyimide resin systems will be developed to provide improved processability for making boron polyimide and graphite polyimide structural components. Present deficiencies in the interlaminar shear strength of graphite fiber reinforced composites will be removed through development of better fiber finishes.

Demonstrate programs of flight and service testing of large size aircraft structural components made of advanced composites will be continued. Increasing use of advanced composites is anticipated under the Air Force's new aircraft prototypes program and by the Army and Navy as well.

The extensive design data generation effort on composites will be continued.

d. Joining and Attachment - Joining and attachment techniques will be improved to achieve increased joint efficiency. All of the weight reductions achieved by improved materials can be lost if highly efficient production joining methods cannot be achieved. This is a particular problem with composites (metal and non metal matrix). The lack of an adhesive which maintained adequate strength after thousands of hours at $600^{\circ}F$ was a factor in deciding to use brazed rather than adhesive bonded titanium honeycomb sandwich on the Supersonic Transport. Thus considerable weight and cost increases had to be accepted. This was also true in the case of the B-70. Had an adequate $500\text{-}600^{\circ}F$ adhesive been available, the B-70

could have avoided the use of welding for the stainless steel honeycomb sandwich. History shows that major cost expenditures were incurred in attempting to weld the sandwich structure. Adhesives will be developed to provide a 600°F capability for long durations at this temperature. Work on new joining techniques to bring them to a production status will be continued.

e. Nondestructive Inspection - This area is critical to achieving high confidence in the reliability of systems, particularly those using new or improved materials. Better methods of finding defects under fasteners without need of disassembly of a structure will be developed. Techniques for inspection of defects will be improved. Methods for determining strength, nondestructively, of bonded joints will be improved. Small portable X-ray units will be developed to permit inspection of relatively inaccessible parts of an aircraft.

f. Systems Applications - The structural materials programs have broad applications to all aircraft, civil as well as military. Cost and weight reduction, improved reliability and fabricability are the ultimate objectives. Obviously these are important to all aircraft. Improvements in aluminum alloys are particularly important to subsonic and near sonic aircraft. Work on titanium alloys will have important payoff to supersonic fighter and transport aircraft and to heavy lift helicopters. Results of advanced composites programs will result in significant improvements in operating cost and performance of all aircraft and particularly STOL, VTOL, and long range transports. The manufacturing technology programs will reduce aircraft fabrication costs and are applicable to all aircraft.

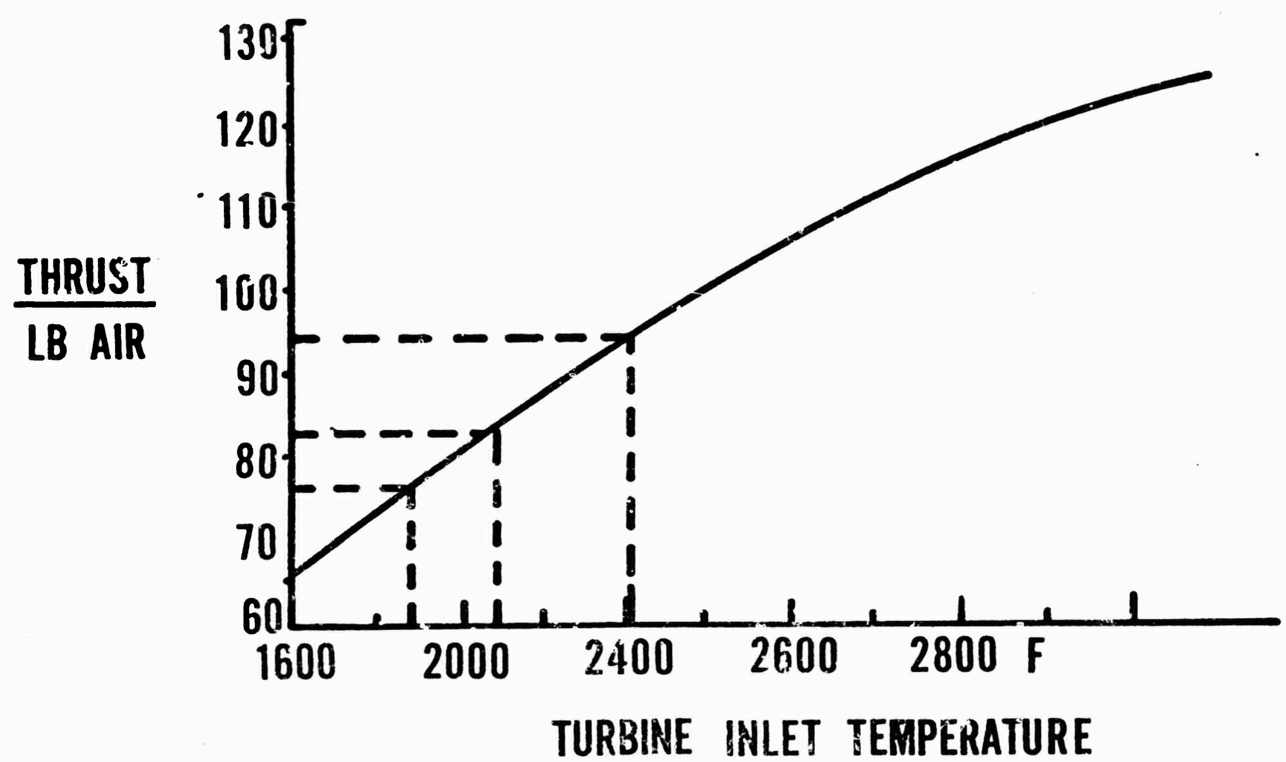
2. Department of Defense Air Breathing Engine Program

The DoD air breathing engine materials program is concerned with applications such as turbojet, turbofan, ramjet, and turboramjet engines as well as heat exchangers, rotors, stator and propeller blades. Strength/density, creep strength, and maximum use temperatures are the primary characteristics of consideration. Other important characteristics are low and high cycle fatigue resistance, thermal stability under service conditions, impact resistance, stiffness, weldability and corrosion/erosion resistance.

Increases in turbine inlet temperatures significantly improve specific thrust and in some cases specific fuel consumption. These improvements result in significant reductions in aircraft takeoff gross weight and also result in reductions in costs. The effect of turbine inlet temperatures (TIT) is plotted in Figure 2. This figure was furnished by NASA. Raising inlet temperature capability from present uncooled levels of about 1850°F to 2100°F as a near term goal and to 2400°F as a far term goal has significant

FIGURE 2

EFFECT OF TURBINE INLET TEMPERATURE



effects on specific thrust. These goals are important to engines for VTOL, STOL, and long range transports.

a. Metal Alloys - Higher strength titanium alloys with increased creep strength which have emerged from the laboratory will be further evaluated to develop optimum processing and joining techniques. These alloys also will be tested to establish thermal stability, oxidation and stress corrosion resistance. Further improvements in dispersion strengthened alloys will be accomplished. These include improvement in oxidation/corrosion resistance and increased strength and temperature capabilities. It is intended to raise the present use temperature ultimately to 2400°F.

Increased durability in engines is being sought through development of longer life coatings for superalloys now used in hot sections (1600-1950°F) of engines. Higher temperature fused slurry type of coatings for columbium for turbine inlet vane applications will be developed. The development of suitable coatings for columbium will enable achieving the goal of high turbine inlet temperatures.

b. Composites - New reinforcement such as single crystal alumina show better retention of strength in composites at high temperatures. An economical production process will be developed to permit further hardware fabrication and testing studies.

Fan blades of higher stiffness to weight will be achieved through the testing of blades made of metal matrix composites. Blades made of directionally solidified eutectics will be rig tested.

Higher temperature composites (eutectics with carbide phase reinforcement, nickel and cobalt base systems) will be further developed by casting and rig testing blades.

c. System Applications - The work on propulsion materials will have application to lighter engines for high performance carrier based VTOL aircraft, heavy lift helicopters for the Army, and high speed advanced fighters for the Air Force.

3. Department of Defense Functional Materials Program

Development of high temperature integral fuel tank sealants with 500°F capability will be continued. Seals for hydraulic systems will be improved to provide better performance at high temperatures - 275-400°F. Improved tire materials to provide up to 500°F capability will continue to be investigated and developed. These tires will have use in advanced manned strategic bombers.

The durability of aircraft tires (cut resistance) under current use conditions will be improved and will reduce maintenance costs of all types of aircraft particularly fighters operating from unimproved runways.

Higher temperature (up to 1000°F) hydraulic fluids will be developed for use on future high performance aircraft.

Better armor materials to protect against 50 cal. and 14.5 mm API projectiles will be developed.

Transparent armor for windshields and view ports will be developed. Higher temperature transparent plastics for use at 500°F canopies for use in future hypersonic vehicles and to possibly refurbish systems such as the F-15 and B-1.

Work to reduce the cost of newly developed cobalt samarium magnets used in traveling wave tubes from $1500/lb to $150/lb will be accomplished.

High temperature insulation materials (good to 2500°F) will be fully characterized with emphasis on durability in vibration and high noise environments to permit their use in hypersonic vehicle systems.

Higher strength inorganic composites (20,000 psi flexural strength) stable at high temperatures (1000-2000°F) will be further evaluated and extensive design data generated. High temperature rain erosion coatings (300-500°F) for composite radomes will be developed and demonstrated.

Extensive engineering and design data will be secured on radar absorbing structures.

Functional fluids for guidance control will be developed to the target properties of 2.5 to 3 grams/milliliter density and a viscosity range of 400-1200 centistokes.

Massive titanium hubs, shafts and spars for helicopter rotor systems with superior fatigue resistance and high toughness are required. Fatigue strengths approach 100,000 psi and toughness (K_{IC}) of 75,000 psi inches are goals. Work in fabrication and heat treatment to achieve these goals will be accomplished. Leading edge materials for rotor blades with good resistance to rain and dust erosion (1500 hours blade life) will be investigated and developed. In service methods of nondestructive inspection of rotor system components will be investigated and evaluated.

4. NASA Structural Materials Program

a. Metal Alloys and Metal Composites - The general goal of NASA programs is to assure structural integrity through attacking the problem areas of fatigue, fracture, creep and environment (stress corrosion).

NASA programs are directed towards improving titanium, aluminum and steel alloys. Emphasis will be placed on titanium because of the future need of advanced transports. Improvements in hot salt corrosion, fracture toughness and weldability will be attempted through alloying, heat treatment and studies of toughening mechanisms, control of microstructure.

Evaluation of the newly developed stress corrosion resistant aluminum alloys will be accomplished.

b. Plastic Matrix Composites - An important objective of NASA structural materials work is to reduce the structural weight of aircraft by 10-30%. The main approach to be used will be combining advanced composites and metal, by adhesive bonding. Materials demonstrations including structural testing and ultimately flight testing of components such as wing carry through structures made of advanced composites bonded to metal in selected areas will be conducted.

Upgrading the long term temperature capability of plastic resins used in composites will be accomplished and demonstrated through generation of properties after prolonged exposures at 600°F.

Studies of the most efficient way of integrating composites into structures or joining of composites to other structures will be made. Testing of typical fuselage skin panels made of composites combined with metals will be conducted.

A prototype composite tank rotor drive shaft for a UH-1 helicopter will be developed, made and tested in a cooperative effort with the Army. Application of composites to the tail cone of the Army CH-54 helicopter will be accomplished and flight testing of this tail cone for about two years will be done. The overall objective of the composites program of NASA will be to enable the production in about 1981 of aircraft consisting of about 50% composites and 50% metal structure. NASA studies emphasize the importance of composites to advanced transports (near sonic and supersonic) and VTOL, STOL civil aircraft.

5. NASA Air Breathing Engine Materials Program

a. Metal Alloys and Composites - The overall objective of the NASA program is to increase the thrust-to-weight ratios of engines. This will be accomplished in various ways. One is through the use of plastic resin matrix composites in cooler sections of the engines (less than 600°F). Prototype fan blades of this type will be made and tested in rigs and engines.

Composite technology is also being applied to metallic matrices such as aluminum. Large (3 mil diameter) carbon monofilaments have been developed with ultimate tensile strengths up to 540,000 psi. These will be used to reinforce aluminum matrices to achieve higher strength, lighter weight composites than materials currently used as blades in the latter compressor stages at temperatures from 600 to 900°F.

Titanium alloy development is also underway to extend use temperature of titanium alloys beyond current limitations of about 900°F. The advances anticipated are to 1150°F by the mid-seventies. The potential application is for the latter-stage compressor blades. Coatings programs are underway to protect titanium alloys against hot salt stress corrosion and oxygen contamination at 900 to 1200°F.

Significant strength advances are being achieved with the application of pre-alloyed powder technology to highly alloyed nickel base materials for use as compressor and turbine disks in the intermediate temperature range up to approximately 1400°F. Conventional wrought superalloys are strength-limited by the amount of alloying content they can contain. This determines whether there will be segregation in the cast ingot and whether the alloys can be forged by conventional techniques. Pre-alloyed powder processing eliminates segregation and forming problems with highly alloyed materials and promises significant advantages over conventional wrought alloys.

Increasing the use temperature capability of superalloys from 1800-2000°F to 2200°F will be achieved through improvement in alloys (compositional changes, and directional solidification). Dispersion strengthening will be applied to high strength superalloys by the NASA Comminution and Blend Technique to further raise use temperature capability to 2400°F and substantially raise the strength level as compared to commercial dispersion strengthened materials such as TD-NiCr which has a relatively weak matrix. The application of composite technology to superalloys will also permit use temperature advances to about 2400°F at stresses suitable for turbine blade application. Refractory metal fibers such as tungsten-hafnium-carbon (W-Hf-C), columbium (Cb), tungsten - 2-volume-percent-thoria (W-2 ThO_2) are being used to reinforce superalloy matrices.

Directionally solidified eutectics will be developed to give even greater strength at these temperatures.

For ultra high temperature applications in advanced turbine engines (2500°F and higher), ceramics such as silicon carbide are under investigation. Reinforcement by means of fibers, yarns, and whiskers should provide significantly improved ductility to these materials and thus make them viable blade materials.

Erosion problems of composite blades will be attacked through the use of imbedded metal screens and shields. Long-term testing of such protected blades will be conducted in rigs and engines.

Present limitations due to corrosion of nickel base alloys will be removed or reduced through exploitation of claddings such as FeCrAlY, and coatings such as complex metal aluminides and combinations of coatings and claddings. Cyclic tests of prolonged duration in high velocity (Mach 1) burner rigs will be made to qualify the use of these coatings for turbine engine blade applications.

Thermal fatigue problems associated with cyclic operation of the high temperature engine components are being attacked by the use of coatings and particularly by directional solidification. Paralleling this effort is the analytical approach for predicting fatigue behavior of high temperature engine components. This seeks to provide techniques for predicting life in advance of service by accounting for the creep and fatigue aspects of material behavior in readily usable prediction methods.

SECTION IV

SUMMARY

The Department of Defense materials programs have resulted in a number of spinoffs to civil aviation. New materials of construction such as titanium, superalloys, and advanced composites have been developed. Today's jet engines were made possible by past DoD materials programs on titanium and superalloys. Many advances in other functional elements of aircraft such as windows, hydraulic fluids, were achieved and are in use. New aircraft fabrication methods and equipment have been developed by DoD which have materially contributed to the progress of civil aviation.

Both DoD and NASA are conducting and planning programs to improve structural efficiency, to increase materials high temperature performance, to reduce fabrication costs, and to better assure structural integrity of aircraft. In structures, reduction in weights is to be achieved through alloy improvement, development and use of composites, increased data generation efforts, and improved joining materials and techniques for metals and composites. Increased reliability is being achieved through extensive design data generation programs, use of fracture mechanics in materials selection, and improvement in nondestructive inspection techniques and equipment. In engines, reductions in weight will be made through the use of plastic and metal matrix composites, and better durability will be achieved through increased toughness, and corrosion and thermal fatigue resistance. Demonstrations and verification of the improvements will be made by establishing a good data base and by building, testing and flying structural components and engines using components reflecting improved materials technology.

The following tabulation summarizes the objectives and systems applications for some of the government's current and planned materials R&D programs.

Objective	Systems & Component Applications
Titanium alloys of higher strength, increased temperature capability, reduced creep, better fatigue resistance, controlled microstructure.	Advanced civil transports, supersonic fighters & bombers, helicopter rotors, hubs, blades, engine components
Aluminum alloys of increased toughness and high stress corrosion	All civil and military aircraft

Objective (Cont'd)	Systems & Component Applications
resistance.	
Superalloys with strength and durability at 2100-2400°F, metal matrix composites, directionally solidified eutectics.	Turbine engine components for VTOL, STOL, and advanced transports
Engineering data on metals and composites.	All aircraft
Advanced composite materials cost reduction, joining studies, flight demonstrations.	VTOL, STOL, advanced transport, and all military aircraft
High temperature radome materials.	Advanced transports, supersonic fighters and bombers
High temperature rain erosion resistant materials.	Advanced transports, supersonic fighters and bombers
High temperature lubricants and hydraulic fluids.	Advanced transports, supersonic fighters and bombers
High temperature transparent plastic materials.	Advanced transports, supersonic fighters and bombers
High temperature tire materials.	Advanced transports, supersonic bombers

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APPENDIX 5

HUMAN FACTORS / AVIATION MEDICINE

JOINT DoD-NASA-DoT
"R&D CONTRIBUTIONS TO AVIATION PROGRESS"
(RADCAP) STUDY

DR. WALTER F. GRETHER
USAF/AFSC (AMRL/CC)
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AUGUST 1972

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SECTION I

INTRODUCTION

The benefits to civil aviation from R&D in Human Factors/Aviation Medicine (HF/AM), unlike those from engineering, generally are not clearly visible in the form of new equipment capabilities. Instead, the benefits come from medical fitness of crew members, and from improved compatibility between hardware and people. As advancements in hardware bring about new crew duties and new flight conditions, these must be matched to the capabilities and limitations of the crew members and passengers. Broadly, the contributions from HF/AM are improved flight safety and health, reduced human errors, improved efficiency in both air and ground operations, and more precise information about human tolerance for noise and air pollution caused by aviation activities. There have also been contributions to human survivability of impacts and escape in emergency evacuations.

Generally the conditions experienced by people involved in military aviation are more severe and hazardous than those typical of civil aviation. Military flying involves very high levels of acceleration (G), extremes of speed, altitude and turbulence, operations in high and low temperatures, and emergency escape in flight. In the process of learning how to deal with such extreme flight conditions military research and development has produced much of the technology needed for the operating conditions of civil aviation.

In order to conduct the necessary R&D in Human Factors/Aviation Medicine, the military departments have acquired outstanding and unique research facilities. Among these outstanding facilities are (1) the Navy centrifuge at Johnsville, Pa. which has been used for clear air turbulence studies, (2) the USAF infra-sound chamber at Wright-Patterson AFB, Ohio, (3) the USAF test tracks at Holloman AFB, New Mexico, used for crash protection studies, (4) the Navy rotating room at Pensacola, Fla, used for studies of disorientation, and (5) the various inhalation chambers used by the USAF for toxicity research at Wright Patterson AFB, Ohio.

This report has concentrated on the benefits to civil aviation from military R&D. While some related contributions of NASA and the DOT/FAA have been included, no attempt was made to include all of these. Also omitted were many significant contributions to problems of military aviation which have little application to civil aviation. Among such contributions were the development of ejection seats and capsules for inflight escape, and the World War II development of Anti-G suits, by Capt John R. Poppen of the US Navy, and his counterparts in the USAF and the Royal Canadian Air Force.

SECTION II

SIGNIFICANT [illegible]VANCES SINCE 1925

a. AIRCRAFT CABIN PRESSURIZATION*

Since the early days of balloon flights in the 1800's it has been known that ascent to altitude causes, in succession, loss of sensory capabilities, impaired judgment, loss of consciousness (at about 25,000 ft.) and finally death. A French physician, Dr. Paul Bert, conducted experiments which demonstrated that these altitude effects were caused by a decrease in oxygen with increase in altitude. Thus, the incapacitating effects could be shifted to higher altitude by breathing supplementary oxygen. Or, they could be avoided entirely by use of a properly pressurized cabin.

(1) Early Developments

Immediately after World War I the U S Army Air Corps became interested in the possible pressurization of the pilot's cockpit as a means of avoiding the harmful effects of altitude. Apparently the first flight of an aircraft with the pilot protected in this way was in 1921. Harold R. Harris, a lieutenant in the U S Army Air Corps, was sealed in a steel tank, with windows for seeing the instruments and the outside. Controls inside the tank operated cables through holes in the tank. A propeller driven unit on the wing provided pressurization. But faulty control of the pressurization system resulted in excessive cabin pressure and temperature (3,000 ft. below sea level and 150°F), and an emergency landing after only 3,000 ft. altitude had been reached.

Listed in table [illegible] the major milestones in the successful development of aircraft cabin pressurization, beginning with the flight by Lt Harris[1]. [illegible] right hand column of the table indicates whether the sponsor of the particular activity was military, a government civilian agency, or the private sector.

The first successful [illegible] of cabin pressurization to overcome altitude were in balloon flights made by Professor Piccard and others during the 1930's. During the same period there was at least one attempt at pre[illegible] an aircraft, flown by Marcel Congo in France. Although [illegible] reached 32,000 ft., the flight ended disastrously, [illegible] due to cabin rupture. The first successful application of [illegible]rization in aircraft was with the Lockheed XC-35, delivered to the U S Army Air Corps in Dayton, Ohio in 1937. In this [illegible] pressurization was provided by

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* For engineering advances [illegible] pressurization see Appendix 6.

** Superscript numbers used here[illegible] subsequently refer to references [illegible] at the end of Appendix [illegible]

TABLE 1. MAJOR MILESTONES IN DEVELOPMENT OF AIRCRAFT CABIN PRESSURIZATION[1]

Date	Event	Sponsor
1921	Lt. Harold R. Harris, US Army Air Corps at Dayton, Ohio flew a De Haviland DH-9, from pressurized tank, to 3,000 ft. A faulty pressure control system caused abort of flight.	Govt/Mil
1931-37	Professor A. Piccard and others made successful balloon flights to 72,000 ft, with pressurized gondolas.	Priv Sect
1937-38	Research by Dr. R. A. McFarland, at Columbia University, for Bureau of Air Commerce, established 8,000 ft. as desirable maximum cabin pressure.	Govt/Civ
1937	Lockheed XC-35, with pressurized cabin was delivered to US Army Air Corps at Dayton, Ohio and flown many times to altitudes of about 30,000 feet. Pressurization was from turbo-supercharger, and was manually regulated.	Govt/Mil
1939-43	Research on explosive decompression at Aero-medical Lab, Dayton, Ohio, established human limits for rate of gas expansion, and time of useful consciousness after pressure loss.	
1940	Boeing B-307 Stratoliner was introduced into airline service by Pan American and TWA. Pressurization was by an engine driven compressor automatically regulated to provide 2.5 psi maximum pressure differential.	Priv Sect
1944	Boeing B-29 Superfortress became operational, using cabin pressurization with 6.55 maximum pressure differential.	Govt/Mil
1946-50	Lockheed Constellation and Douglas DC-6, using cabin pressurization, were introduced into airline service.	Priv Sect

turbo-superchargers incorporated into the engines, and the pressure was manually controlled. Repeated flights were made to altitudes around 30,000 ft.

Guiding the work of engineers and aircraft manufacturers was the research by Aviation Medicine specialists, both military and civilian, which provided the human tolerance criteria for the pressurization conditions. An important question for the aircraft designers was the pressure, or cabin altitude, which the pressurization system should provide. It was primarily the research by Dr. R. A. McFarland[1], working at Columbia University from 1937 - 1938 under a contract from the Bureau of Air Commerce, which established 8,000 ft. as the maximum altitude for cabin pressurization. With increases in altitude above this value, passengers and flight crews begin to suffer increasing impairment. This 8,000 ft. value has been the standard limit used for both military and civilian aircraft.

Considerably more complex were the questions related to the hazards from a sudden loss of pressure, if a window or other section of the cabin should fail. How rapid a pressure change can people tolerate without injury? Also, after the pressure is lost, how long will persons remain conscious and be able to carry out emergency procedures, such as the application of oxygen masks? Answers to these questions were provided by U S Army Air Corps research at the Aeromedical Laboratory, at Wright Field, between 1940 and 1943. These research data guided the aircraft designers in making choices concerning safe flying altitudes, cabin (vs outside) pressure differentials, cabin window sizes, and emergency oxygen requirements.

Following the successful flights of the XC-35, and concurrent with the important aviation medical studies, the Boeing Aircraft Company built the B-307 Stratoliner, with a 2.5 psi cabin pressure differential. This permitted flights up to 15,000 ft., while maintaining the cabin at 8,000 ft. Both Pan American and TWA used this aircraft in airline service beginning in 1940.

More advanced cabin pressurization was applied in the Boeing B-29, used in the Army Air Corps in the Pacific, during the late phases of World War II. This aircraft used a 6.55 psi cabin pressure differential, permitting flight up to 30,000 ft. with the cabin at 8,000 ft. Following soon after the B-29 were the well known Lockheed Constellation and Douglas DC-6 passenger aircraft, used for many years by the commercial airlines.

(2) Flow of Technology

As can be seen in Table 1, there were concurrent research

and development activities in both the military and civilian sectors, with rapid interchange of technology. Although the military efforts played a leading role, there were no significant delays in civilian use and improvements on military technology.

(3) Civil Aviation Benefits

The successful development of cabin pressurization, along with other aeronautical advances, made it possible to fly at much higher altitudes without the use of cumbersome oxygen masks. These higher flight altitudes avoid much of the bad weather and turbulence associated with lower altitudes, thus making air travel more acceptable to passengers. Also, flight in the less dense upper atmosphere results in significant operating economies.

(4) Subsequent Developments

During the early years of pressurized passenger aircraft there were occasional disasters and emergencies caused by loss of cabin pressure. Best known were the mishaps with the British Comet aircraft. However, improvements in structures technology have largely overcome such problems, and pressure cabin failure is now a very uncommon event.

As technology has improved, the commonly used pressure differential between the cabin and the outside has increased from 2.5 psi in the early Boeing B-307 to 9.0 psi or more in modern jet transports[2]. In aircraft with such higher cabin pressure differentials it is customary to maintain the cabin altitude at 6,000 ft. or less, rather than the 8,000 ft. used previously.

For the higher altitudes at which supersonic airliners will operate, even higher cabin pressure differentials are necessary than the 9.0 psi now commonly used in subsonic jet passenger aircraft. Also, as altitudes are increased above those currently in common use, the dangers from a sudden loss of cabin pressure become extremely critical. Above about 25,000 ft. persons will quickly lose consciousness, unless breathing supplementary oxygen by mask. Above about 45,000 ft. even this will be inadequate to sustain consciousness and life. Thus if pressure should be lost the aircraft must descend as quickly as possible to lower altitudes. These problems have been well understood since the Aviation Medicine research performed during World War II, and existing data provide the necessary human criteria for planners of supersonic transports.

b. NOISE EFFECTS ON CIVILIAN POPULATIONS

1. Hearing Conservation

(1) Early Developments

The effectiveness of aircraft noise in masking voice communication and in eventually causing deafness has long been recognized. The aviation era introduced more intense noise sources in greater numbers causing increased alarm about possible adverse effects on aircrews and ground crews.

The first systematic approach to the aircraft noise problem occurred at the Psychoacoustics Laboratory, Harvard University during World War II under the direction of Dr. S. S. Stevens. Studies of hearing, hearing protectors, communications and performance in propeller type aircraft noise provided substantial guidance for aviation. The widespread introduction of jet engine aircraft, with noise exposures of different character and greater intensity, necessitated new major R&D efforts. The USAF initiated a broad research program in 1945 to define effects of intense noise on aircrews and groundcrews. Table 2 lists some milestones in the hearing conversation/noise effects area. "Rumored severe effects" of ultrasound on groundcrews were dispelled, preliminary exposure criteria were formulated and a hearing protector development program initiated.

Two publications in 1953 summarized the state-of-the art; a first comprehensive Handbook of Noise Control[3] which considered the overall aircraft noise problem and the Benox report[4] which summarized biological effects of intense aircraft sound on man. Criteria which specified maximum permissible levels for short time exposures on personnel to intense jet noise were published by the USAF. The first complete hearing conservation program in the United States, based on all prior research and development, was implemented by the USAF in 1956.

The first effective earmuff type hearing protector was developed jointly by the USAF and the David Clark Company. This basic device was further developed into a system which provided excellent ground communication in the most intense aircraft noise by incorporating earphones and a noise shield for the microphone. Both type units were procured by the civil aviation industry for use by their groundcrews.

Aircrews experienced problems involving the masking of voice communication by noise and risk of hearing loss due to excessive exposure. In-flight headsets and helmets were modified to improve sound protection and a Military Specification[5] was established to limit noise exposure in occupied areas in aircraft to within acceptable limits. This specification[5] was revised in 1956 to account for long duration flights and to take advantage of better sound protectors.

TABLE 2. MILESTONES IN HEARING CONSERVATION

Date	Event	Sponsor
1941-45	Psychoacoustic Studies of Aircraft Noise Effects at Harvard University	Govt/Mil
1945	Establishment of Air Force Psychoacoustic R&D Capability	Govt/Mil
1952	First Comprehensive Handbook of Noise Control[3] Including Hearing Loss Criteria, Hearing Protectors, Voice Communication	Govt/Mil
1953	Benox Report, Exploratory Study[4] assessed state of the art and recommended course of action to insure performance effectiveness in very high intensity noise and no adverse biological effects.	Govt/Mil
1954	Acoustical Noise Levels in Aircraft Criteria[5] were established to control noise exposure in occupied space in aircraft to within safe levels. Mil Spec A-8806	Govt/Mil
1955	Established Short Duration Exposure Criteria for Personnel in high Intensity Jet Noise	Govt/Mil
1956	First comprehensive hearing conservation program in the United States, implemented by the USAF and establishment of USAF Hearing Repository	Govt/Mil
1960	Physiological limits of hearing protection were defined, confirming earlier calculations	Govt/Mil
1964-68	Relative risk levels were defined for intense impulsive type acoustic stimuli	Govt/Mil & Civ
1968	Aircraft Cabin Noise Criteria were updated to include long duration flights and better sound protectors (Mil-A-8806B)	Govt/Mil & Civ
1969	Publication of Federal Standard on Permissable Noise Exposure	Govt/Civ
1971	Proposed revision and updating of current USAF hearing conservation criteria and program	Govt/Mil

An extensive exploratory study of effects of intense infrasound (acoustic energy below 100Hz) on various human responses provided determinations of tentative exposure criteria limits. As the size of aircraft propulsion increases, the amount of intense low frequencies and infrasound also increases. A unique facility was designed and constructed to provide intense whole body exposures to infrasonic energy as part of a recently initiated USAF program to investigate possible harmful effects of these new and different noise environs generated by larger propulsion systems as used on the C-5A and Boeing 747 aircraft.

In 1971 a proposed revision[6] of the 1956 USAF regulation on Hazardous Noise Control was prepared, incorporating several advances in the technical area of noise exposure criteria. New concepts include the use of a single number to define noise exposure (dBA); infrasound, ultrasound and impulsive sound exposure criteria and various intermittent exposure schedules. The basic criterion is 85 dBA, 5 dBA less than the current federal criterion of 90 dBA.

(2) Flow of Technology

The military sponsored research in this problem area clearly provided the broad base and most of the specified knowledge subsequently utilized by the civil sector, sometimes directly and sometimes in modified version, to combat adverse effects of aircraft noise on personnel. Some of the significant events contained in Table 2 represent concurrent activities in both military and civil sectors resulting in technical information and breakthroughs of common interest to both. Air Force scientists in key roles on earlier National Advisory Committee for Aeronautics (NACA) noise committees and now on Department of Defense (DoD) national and international committees combating noise effects clearly expedite the flow of technology.

(3) Civil Aviation Benefits

Today virtually all of the civil aviation industry employs a hearing conservation program of some type. The very first program, which included determination of noise exposure, hearing protection and monitoring audiometry, was implemented by the USAF in 1956. All hearing conservation programs follow the same pattern either directly or in modified form.

Various other exposure criteria found in the USAF have also been used in civil industry. The major empirical work on ultrasound effects on man was accomplished by USAF prior to 1950. Muff type hearing protectors and ground communication units were procured

by civil aviation as soon after development as they were available. Research on effects of infrasound and on effects of noise combined with other stresses is being accomplished only by USAF. As in the past, the military has needed R&D first and the civil sector has benefited from the successful military programs.

(4) Subsequent Developments

Responses of the human auditory system to acoustic energy have become successively better understood as early developments were improved upon. Initial exposure criteria specified broad octave band values; development has progressed to the present technology where permissible exposures are expressed in terms of single numbers (dBA). dBA values are obtained using instruments designed to approximate the response of the human ear. Use of dBA significantly decreases the resources necessary to evaluate a noise exposure for hearing conservation purposes. Acoustic design work still requires more complex descriptions of the noise.

Hearing protector development has reached a plateau with respect to increases in sound attenuation. Some years back, very few hearing protectors provided good protection. Today many effective devices are available and improvements, if they occur, are expected in areas of comfort, wearability and durability.

Hearing conservation problems in typical aircraft noise have been well understood for some time and available criteria clearly describe exposure limitations. Criteria are not confirmed for impulsive sound, for infrasound and for various irregular exposures.

2. Land Use Planning

(1) Early Developments

Prior to 1945 aircraft engine power levels were low and community disturbance by aircraft noise was relatively uncommon. In the post World War II era, with the introduction of jet engines, noise intrusion into communities became a substantial problem. The USAF initiated a broad, new aircraft noise research program, effectively coordinated with other agencies and with industry, to control aircraft noise in the community. Research on engine noise, noise suppression, bioacoustics problems and community reaction have continued. Table 3 presents some milestones in the development of land use planning procedures.

TABLE 3. MILESTONES IN LAND USE PLANNING

Date	Event	Sponsor
1952	First Comprehensive Handbook of Noise Control[3] included first scheme for estimating community reaction to aircraft noise.	Govt/Mil
1957	First detailed procedure[7] for estimating noise exposure and resulting community reaction from airbase operations; also noise exposure Criteria for Work and Living Spaces; both widely used by civil sector.	Govt/Mil
1961	A joint USAF-NASA Hazards Study determined population effects of noise from rocket launches of vehicles up to NOVA class; results showed that Cape Kennedy was satisfactory site from community noise standpoint.	Govt/Mil & Civ
1962	Concept of "noisiness" was established as a subjective measure of acceptability of aircraft noise by Dr. Karl Kryter.	Priv Sect
1965	An updated version of the USAF procedure for estimating community reaction to aircraft noise was adopted as a tri-service manual and by FAA as well as HUD and FHA.	Govt/Mil & Civ
1969	Program initiation to update land-use-planning guide to include all USAF and USN aircraft.	Govt/Mil
1969	FAA Noise Certification of Commercial Aircraft	Govt/Civ

In 1953 the first procedure[5] for estimating effects of aircraft noise on communities was formulated. Two years later a USAF regulation established air base operating procedure limits to minimize exposure of the population. A decade of extensive research in this area reached a peak in 1957 when several technical achievements were realized. Among them, results of community reaction to aircraft noise studies sponsored first by NACA and then by USAF, a step-by-step guide for estimating noise exposure and community reaction, acoustical criteria for aircraft noise intrusion into work and living spaces, and a commercial handbook of Noise Control[7] in which USAF scientists prepared comprehensive sections on aircraft noise sources, noise control and community reaction. Later, in 1962, criteria for acoustical performance of aircraft noise suppressors were established.

In 1962-1963 the concept of "noisiness" was established by Dr. Karl Kryter as a subjective measure of acceptability of aircraft noise which could be calculated from physical measurements of the noise. The noisiness concept was incorporated into the USAF Land Use Planning document[8] in 1963-1964 which was adopted as a tri-service manual. The FAA adopted and continues to use this same procedure for land use planning purposes as does the Department of Housing and Urban Development (HUD) and the Federal Housing Administration (FHA).

Research has continued since that time to better define effects of discrete tones, of duration of the noise and of other factors in the noise exposure situation. The present technology provides a good base for establishing community exposure criteria and USAF efforts are directed toward revising land use planning guidelines to include this technology. This is a general procedure which can be used with any aircraft. The current effort will include USN aircraft in the guide and it is expected that the FAA may adopt the revised procedure for civilian aircraft upon its completion.

The land use planning guide is an effective tool for minimizing and eliminating adverse effects of noise in the community. It will continually be updated to include new aircraft and to incorporate improvements in the technology which will increase the probability of accurately estimating community response.

(2) Flow of Technology

The USAF played and continues to play a leading role in the development of land use planning procedures. Close coordination has been maintained with FAA and with NASA with no significant delays in exchange or transfer of information. The current land use planning guide was simultaneously adopted in [illegible] by both the USA and USN. The FAA, HUD and FHA also utilize the same procedure for land use planning

purposes. Technical information is also distributed via groups such as the Interagency Aircraft Noise Abatement Program; Armed Forces National Academy of Sciences Committee on Hearing, Bioacoustics and Biomechanics and the American National Standards Institute of which USAF scientists are key members.

(3) Civil Aviation Benefits

Civil aviation has directly benefited from military efforts throughout the research and development programs which have resulted in the current land use planning procedure. Each development has been utilized by the non-military sector at each step of the way. The land use planning technology has made it possible for land areas in the vicinity of airports to be evaluated and planned for uses that are compatible with noise exposures. Possible uses of open spaces may be identified, effects of changes in runway utilization on community reaction may be assessed as can the severity of exposures of existing communities. Residential dwellings near airports must now have minimum noise insulation features to qualify for financial assistance from Federal agencies such as HUD and FHA. This procedure does not eliminate existing problems. It may be used to understand and possibly minimize them, and most important, to avoid the creation of new ones.

(4) Subsequent Development

During the early years of jet aircraft, procedures were not available for assessing community reaction to aircraft noise. The initial development of such a scheme appeared first in 1952 and subsequently as an improved version in 1957. The technology base broadened to include community response studies, and the concept of subjective "noisiness" or perceived noise level and in 1965 the present procedure was established and immediately was widely adopted.

Development has continued in the direction of further refining present guidelines and of including all aircraft in use. Increased definition is sought regarding parameters such as pure tone corrections, duration effects, time of day and any other change in exposure which might affect acceptability. Plans are in effect to modify the current procedure to include the data acquired since 1965. The USAF has pioneered development of land use planning and the magnitude of aircraft noise problems necessitates a continuing, active development program to keep pace with advances in aviation technology.

3. Sonic Boom

(1) Early Development

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Mysterious "explosive-like" sounds experienced at Wright-Patterson AFB, Ohio and in neighboring communities in 1950 were discovered to be sonic booms generated by F-86 aircraft dives which exceeded the speed of sound. Questions regarding the nature of sonic boom generation and propagation and possible hazardous effects on structures, animals and people did not emerge until the mid-50's when sustained supersonic flight became a reality with the appearance of high performance aircraft. Listed in Table 4 are some major milestones in the development and treatment of the sonic boom problem beginning with the discovery of the sonic boom.

During the early 1950's the number of high performance aircraft gradually increased and the percentage of the civilian population exposed to sonic booms rose. Complaints of unacceptability and claims of damage to personal property increased. Joint research programs, initiated in this period and continuing into the 1960's, accomplished by the USAF and NASA defined the physical characteristics of sonic boom and potential effects on structures. NASA/USAF tests[9,10] in 1958-1961 investigated sonic booms generated from altitudes of 50 ft to 75,000 ft. Subsequently, sonic boom predictive schemes were formulated and sonic booms measured in the field correlated well with predicted values.

Primary impetus for sonic boom research shifted from USAF to FAA and NASA in the 1960's as a consequence of the National Supersonic Transport Development Program. The possibility of numerous supersonic flights daily over a community represented more severe exposures than those from occasional military flights. A level of sonic boom exposure below which no adverse reaction would occur was sought. Laboratory, field and community overflight programs were accomplished to define sonic boom effects on people under simulated supersonic flight profiles toward this end. Project Littleman, at Edwards AFB, demonstrated that sonic booms did not affect either the aircraft or the pilot of small, light aircraft.

In 1964 Oklahoma City was exposed to eight sonic booms daily over a six month period in the most comprehensive study[11] of its kind. Results confirmed general USAF experience and the earlier St. Louis study[12] findings which identified basic patterns of reaction to sonic booms by individuals and communities and which showed that significant percentages of the exposed populations felt they could not learn to live with several sonic booms daily. Knowledge of effects of sonic booms on structures and people were not conclusive. However, it was clear that a "single level" of sonic boom below which no adverse response occurs was not a feasible concept.

Additional studies[13,14] were conducted at White

TABLE 4. MAJOR MILESTONES IN SONIC BOOM RESEARCH

Year	Event	Sponsor
1950	Discovery of sonic boom.	Govt/Mil
1954-60	Theoretical and experimental investigations of sonic boom generation, propagation and effects on structures.	Govt/Mil & Civ
1961-64	Studies[11,12] of community reaction to sonic boom (St Louis and Oklahoma City)	Govt/Mil & Civ
1965&70	Comprehensive sonic boom symposia	Govt/Mil & Civ
1967	Exposures of humans to maximum overpressures of 144 psf[14]	Govt/Mil
1966-68	Psychoacoustic studies compared acceptability of A/C flyover noise to sonic booms	Govt/Mil & Civ

Sands, N. M., in 1964-1965, of responses of residential type structures to sonic booms and at Edwards AFB, 1966-1968, of comparative responses of human volunteers to sonic booms vs noise from aircraft overflights. Prior exposure to sonic boom and subsequent adaptation resulted in more acceptability of booms, however, significant proportions of the subjects judged the sonic booms to be unacceptable.

In spite of the vast amount of experience and knowledge available on sonic boom, the degree to which a commercial supersonic transport would be accepted by the population cannot be determined at this time.

(2) Flow of Technology

The sonic boom originated with and remained a USAF problem in the early 1950's because no other agency possessed vehicles capable of supersonic speeds. In the late 1950's and beyond, most sonic boom research programs were accomplished through the cooperative efforts of the USAF/NASA/FAA, with civilian contractor support on some efforts.

The USAF provided aircraft support for almost all studies. F-80 and F-100 series fighter aircraft as well as B-58 and SR-71 vehicles have been involved. Some studies at Edwards AFB utilized the XB-70 aircraft, which provided the best simulation of proposed commercial supersonic transports.

Research results have been simultaneously available to all three primary agencies, DoD, NASA, and DoT/FAA as well as others. Typically, informal interchange of information between on-site project personnel resulted in no delays in transfer of information. The cooperative attitudes and willing exchanges of technical information among the agencies involved facilitated the progress that has been made in this area.

(3) Civil Aviation Benefits

USAF experiences with supersonic flight, sonic boom effects on structures, animals and people have been directly utilized by nonmilitary agencies in formulating decisions regarding commercial supersonic research and development. Air Force records of sonic boom exposures which resulted in complaints and claims of damage to property were used to allow estimates of potential effects of supersonic flights to be made. USAF procedures for investigating and processing claims of damage were utilized in the community studies. Proposed commercial

flight profiles and air routes were formulated relative to sonic boom magnitude on the ground and estimated effects. The knowledge acquired by civil aviation in France and the United Kinodom as well as the U.S. has been possible because the military has provided supersonic overflights for the various programs. It appears that the decision to cease SST development was strongly influenced by the sonic boom, and the incomplete state-of-the-art which prevents total assurances of no adverse effects on communities.

(4) Subsequent Developments

Research on community acceptance of sonic booms advanced sharply in the early and mid-1960's, and leveled off by the end of the decade. Early developments were pursued in a logical manner to provide the current technological base. Sonic boom research continues in NASA and FAA, as well as the USAF. In time, the British-French and the Russian supersonic transports may be requesting permission to fly into and over land areas of the United States. Also, the USAF will continue to maintain supersonic vehicles for national defense purposes, in which crew members must be trained at supersonic speeds. Thus, sonic boom exposures remain as a problem for the future.

The sonic boom question has not been fully resolved. It is complex, involving the attitudes, opinions and beliefs of exposed populations as well as the interference effects of the boom itself. Although a predictive scheme is not in use, past research and experience provide a good base for estimating the unacceptability of individual exposures. An acceptable level of sonic boom exposures has not been found.

Throughout the development of sonic boom technology, cooperative efforts by both the military and civilian sectors have been the rule. This cooperation, especially in sharing technical information, continues in the current program efforts.

(5) Costs

The total annual costs of military R&D on the effects of noise on people (including Hearing Conservation, Land Use Planning, and Sonic Boom) is estimated to be about $750K.

c. AVIATION MEDICINE FOR CIVIL AVIATION

Aviation Medicine[2], also called Aerospace Medicine, is a specialty in the field of professional medicine, with the objectives of flight safety, and health and effectiveness of flight personnel.

Supporting and associated with it are many other related scientific specialties, among them physiology, internal medicine, ophthalmology, otology, neuropsychiatry and psychology.

(1) Early Developments

General Theodore Charles Lyster, Medical Corps, U. S. Army, who was subsequently to become known as the father of Aviation Medicine in the United States, was one of the first individuals to realize the importance of medical problems related to flying. In September 1917, General Lyster became the first Chief Surgeon, Aviation Section, Signal Corps, U. S. Army, and during World War I guided the development of Aviation Medicine, particularly pilot selection, aviation medical research and the organization of medical support for air units. In May 1917 standards and regulations concerning the physical examinations of pilots were issued, and on 18 October 1917 the Aviation Medical Research Board was established. The functions of the Board were to investigate conditions which affect the efficiency of pilots, to institute and carry out such experiments and tests as would determine the ability of pilots to fly at high altitude, to carry out experiments and tests to provide suitable apparatus for the supply of oxygen to pilots at high altitudes and to act as a standing medical board for consideration of all matters relating to the physical fitness of pilots. In January 1918 the Board established the Air Service Medical Research Laboratory at Hazel Hurst Field, Minneola, Long Island. This and subsequent milestones in Aviation Medicine are shown in Table 5. This laboratory contained a low pressure chamber which was used to study the effects of hypoxia and to evaluate pilots with regard to altitude tolerance, (oxygen equipment for aircraft was not available at that time). Another function of the laboratory was the study of physical standards for flyers. The importance of adaptability and suitability for flying was also recognized and in 1923 Longacre developed a comprehensive personality study for use in selecting aviation cadets. Ophthalmological studies at the laboratory included color vision, visual acuity, eye muscle balance, fields of vision and depth perception testing under normal conditions and during simulation of high altitude. The work in depth perception resulted in the development of the Howard-Dolman depth perception apparatus which is still in use today.

Realizing the need for specialization in the field of Aviation Medicine, in May 1919 General Lyster established the School for Flight Surgeons which was the antecedent of the USAF School of Aerospace Medicine currently located at Brooks AFB, Texas. Following World War I, interest in Aviation Medicine declined; and was, in fact, maintained solely by the School of Aviation Medicine. However, as both commercial and military aviation expanded, interest in Aviation

TABLE 5. MILESTONES IN THE DEVELOPMENT OF AVIATION MEDICINE

Year	Event	Sponsor
1918-19	Air Service Medical Research Laboratory, and first school for flight surgeons	Govt/Mil
1926	First textbook in Aviation Medicine	Govt/Mil
1926	Medical Section, established in Bureau of Air Commerce	Govt/Civ
1929	Aeromedical Association formed	Govt/Mil & Civ
1934	Aeromedical Research Laboratory at Wright Field established	Govt/Mil
1936	First airline medical department established by Eastern Airlines	Priv Sect
1939	Collier Trophy awarded to airlines of U. S. for high record of safety, with special recognition to W. M. Boothby, W. Randolph Lovelace II, and H. G. Armstrong for work in Aviation Medicine	Priv Sect & Govt/Mil
1944	Airline Medical Directors Association established	Priv Sect
1953	Board certification in Aerospace Medicine approved	All
1958	FAA Civil Aeromedical Research Institute established, at Oklahoma City (Now Civil Aeromedical Institute)	Govt/Civ

Medicine was revived. In 1926 a medical section in the Bureau of Air Commerce of the Department of Commerce was established. Lt Col Louis H. Bauer, former Commandant of the Army School of Aviation Medicine and the man who in 1926 wrote the first American textbook on Aviation Medicine, resigned his commission to become the first Medical Director of the Aeronautics Branch of the Bureau of Air Commerce in November 1926. This Bureau was concerned with civil aviation and required applicants for civil aviation licenses to pass a prescribed physical examination.

One of the first problems facing Dr. Bauer involved the determination of physical standards to be used in licensing civilian pilots, and another was the selection of physicians with adequate qualifications to conduct the examinations. The initial physical standards proposed by Dr. Bauer represented a modification of the Army Air Corps physical requirements. On 20 November 1927, a group of 57 physicians from 21 states and the District of Columbia were selected to act as medical examiners. It soon became apparent to Dr. Bauer that these physicians, although well versed in their medical specialities, required further training in the field of Aviation Medicine. Therefore, at a conference held in Washington, D.C., on 15 December 1928, it was decided to establish an organization of physicians concerned with Aviation Medicine. Thus the Aeromedical Association was formed.

The first meeting was held in Detroit, Michigan, on 7 and 8 October 1929, with the initial group consisting of approximately 60 physicians. Dr. Bauer became the first President of the Association and served as editor of its Journal of Aviation Medicine for a period of 25 years. On 30 April 1959 the name of the organization was changed to the Aerospace Medical Association and the name of the Journal was also changed to Aerospace Medicine. The membership of the association now numbers in excess of 3,000 individuals, approximately 10% of whom reside in foreign countries. Membership is not limited to physicians but is composed of representatives, both military and civilian, of all disciplines devoted to the clinical and research aspects of Aerospace Medicine.

In 1935 the Physiological Research Unit (which later became the Aeromedical Research Laboratory) was established at Wright Field, Dayton, Ohio and headed by Captain Harry A. Armstrong. The purpose of the laboratory was to perform studies to evaluate the human effects of high performance flight and to develop methods of overcoming those factors detrimental to the health, safety or performance of flying personnel. In 1939 the United States Navy School of Aviation Medicine, Naval Air Station, Pensacola, Florida, was established.

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An important development in civil Aviation Medicine which occurred at approximately the same time, was the establishment of medical departments by several aircraft manufacturers and commercial airlines. The primary responsibility of these medical departments was to provide aeromedical service to the flight personnel of the companies involved. However, additional service provided included consultation to aircraft manufacturers with regards to human factors, engineering and the establishment of a program to promote the health and safety of airline passengers. The first airline medical department within the confines of the continental United States was established in Miami, Florida, by Eastern Airlines on 1 July 1936. The first Medical Department Director of Eastern Airlines was Dr. Ralph Greene. Other airlines rapidly followed suit and on 3 September 1944 the Airline Medical Directors Association was formed with Col Arnold D. Tuttle, Medical Director of United Airlines, elected as the first president of the association. The constitution adopted by the members included the following objects: "(1) to improve the practice and standards of aviation and industrial medicine, particularly as pertaining to domestic and international air operation, and to encourage research and study of medical problems in these fields; (2) to aid in the establishment and support of any scientific or benevolent associations or institutions which are inaugurated to further objects of the association; and (3) to stimulate and foster mutual help and friendship and accomplishment of the objects herein set forth." Membership of the group was limited to physicians and surgeons who were members of the medical departments of commercial airlines devoting either part or full time, or in the capacity as a consultant or other scientist who had contributed to the practice of aviation in civil airlines.

Following World War II, because of the maintenance of a standing Air Force and because of rapidly expanding civil and commercial aviation, Aviation Medicine continued to advance in importance. With the advent of the Korean War and the widespread combat use of jet aircraft, additional aeromedical problems associated with jet aircraft escape systems once again emphasized the need for specialists in Aviation Medicine and in aeromedical research.

Aerospace Medicine was first recognized as a distinct medical specialty on 8 February 1953 when Board certification in Aerospace Medicine was approved. The American Board of Preventive Medicine was empowered to issue certification to qualified applicants. Between November 1953 and October 1954, a founders group of 159 physicians was certified without examination. The first examinations for qualified applicants for certification in Aviation Medicine were March 17 through 19, 1955. Residency training programs in Aerospace Medicine, leading to Board eligibility are currently provided by the U. S. Air Force, U. S. Navy, the Department of Preventive Medicine at Ohio State University College of Medicine, and by the School of Public Health, University of Oklahoma.

The office of Civil Air Surgeon (later Federal Air Surgeon) was established in the new Federal Aviation Administration in 1958. This office supervises the practice of Aviation and Aerospace Medicine with regard to civil aviation, and has responsibilities including conducting physical examinations. The Federal Air Surgeon also has the responsibility for the health maintenance of air traffic control personnel. The Federal Aviation Administration Research Program is conducted at the Civil Aeromedical Institute in Oklahoma City, Oklahoma. This facility includes four laboratories which are devoted to protection and survival, physiology, psychology, and pharamcology-biochemistry. The Federal Air Surgeon is also charged with the responsibility for education programs for FAA medical personnel, for civilian flyers and for a physiological training program.

(2) Flow of Technology

Throughout the history of Aviation Medicine, much of the leadership and progress has come from military flight surgeons, in the United States, England, Germany and other western nations. Significant contributions have also come from civilian laboratories such as the Mayo Clinic, the University of Southern California, Ohio State University and the CAA Civil Aviation Medical Research Laboratory at Columbus, Ohio (Established in 1948). Since 1958 major contributions have come from the FAA Institute at Oklahoma City.

Much of the transfer of technology has been through schools of Aviation Medicine operated by the Navy and Air Force. Many graduates of these schools have later been employed in civil aviation. More recently, residency training in the specialty of Aviation Medicine is also provided at Ohio State University and the University of Oklahoma. Other mediums for the transfer of technology have been the annual meetings of the Aerospace Medical Association, and the technical journal of that association.

(3) Civil Aviation Benefits

Civil Aviation Medicine personnel set physical (medical) standards for flight and air traffic control personnel, and provide periodic medical examinations to assure fitness of these personnel to perform their critical duties. Medical personnel also participate in accident investigations to find causes of accidents and injuries, and to develop corrective measures. There are certain types of diseases or health conditions which could be aggravated by air travel, concerning which medical decisions are required.

(4) New Developments

As civil aviation enters new flight conditions, such as

those associated with a supersonic transport aircraft, Aviation Medicine provides an evaluation of and solutions to possible threats to health and safety. A supersonic transport, because of the higher flight altitudes, does introduce a much increased hazard from rapid loss of cabin pressure, as discussed earlier in Section a. There are also new threats from ozone and ionizing radiation at the most efficient altitudes for supersonic flight. Aviation Medicine research has studied these hazards and found them to be within safe tolerance limits. Also, the USAF has had considerable operating experience in reconnaissance flights at very high altitudes, under the careful monitoring of Air Force flight surgeons.

d. TOXICITY OF AVIATION MATERIALS

The rapid developments in chemical engineering and technology have had a major impact on aviation. As soon as new structural materials, propellants, working fluids, and other useful industrial chemicals became available, unique and novel applications became evident in the areas of airframe structures, propulsion, cockpit and cabin design, rescue and survival and, last but not least, aviation and ground safety. Because of the high performance requirements typical of military aircraft, such new materials and chemicals were usually first exploited in the design of airborne weapon systems and once their value was proven, they were employed gradually by commercial and civil aircraft designers. The biological information on potential health hazards involved in the use of these materials had to be developed as an integral part of systems R&D. Human tolerance limits had to be established for the materials themselves as well as the eventual breakdown products which are the result of either normal degradation or thermal stresses and combustion. These tolerance criteria had to consider the chemical safety of research, manufacturing, and operating personnel, on the ground and in the air, and the overall safety of crews and passengers.

(1) Early Developments

Toxicological evaluation of new chemicals and additives began with the advent of jet propulsion with the USAF having the primary responsibility in DoD. In the period from 1952 to 1962 the following types of materials were carefully studied:

High temperature lubricants and greases

High temperature hydraulic fluids

High temperature engi fuels and oils

Chemical stabilizers and additives

Pyrolysis products from above materials

Deicing fluids

Fire extinguishants and pyrolysis products

Structural and other applications of beryllium

Results of these studies laid the groundwork for the development of safe industrial hygiene, occupational and aviation medicine guidelines. Moreover, the toxicology studies of degradation and pyrolysis products have facilitated sound engineering and design tradeoffs to increase aviation safety. Specific attention was directed toward those contaminants which could endanger crew and passenger safety by entering the pressurized cabin atmosphere.

(2) Flow of Technology

All of these findings were published as Technical Reports and approximately 20 such documents were widely distributed to the aircraft industry.

(3) Civilian Aviation Benefits

The main benefit from toxicological studies lies in the fact that the information is available and is equally beneficial for the protection of military and civilian populations. Since the results were available, commercial and civilian aircraft designers did not have to spend time and money to develop the tolerance criteria.

(4) Subsequent Developments

There is a continuing military R&D effort in aviation toxicology. Since 1962, this effort has been primarily concerned with the toxicology of new (space-age) materials which are finding their way into various aircraft technology areas. Increased emphasis is now placed on fire and other safety aspects for cabin interior design, improved fire extinguishants and toxicity of smoke constituents during in-flight fires or on emergency landings. Such studies are of crucial importance to increased survivability of crews and passengers upon crash landing, and in maintaining optimum crew performance to effect safe emergency landings. Since 1970, the Civil Aeromedical Institute (CAMI) of the FAA in Oklahoma City is cosponsoring these studies by transferring funds on a cost sharing basis.

(5) Civil Advances

The FAA Civil Aeromedical Institute has been conducting and sponsoring pioneering toxicology research on the aviation safety aspects of crop dusting, drug effects on pilot performance, and drug induced pilot fatalities. Results of this research are of direct applicability to military Aviation Medicine. This Institute has also measured and reported the toxic by-products of burning aircraft materials. More extensive measurements have been made and reported by the National Bureau of Standards under FAA sponsorship. As newer materials become available either commercially or experimentally these efforts are continued.

(6) Costs

The annual cost of military R&D on toxicity of aviation materials is estimated to be approximately $150K.

e. MAN/MACHINE INTERFACE FOR AIR AND GROUND SYSTEMS

Among the lessons learned in World War II was a realization that much aviation and other military equipment was poorly designed to match human capabilities and limitations. Because of this general deficiency the losses of military aircraft through human error were excessive, and combat efficiency in such vital areas as strategic bombing was far below the capabilities of the equipment. As a consequence, during the demobilization period several military research teams were established to attack this general problem. From the work of these post-war teams, staffed largely by psycholcgists, grew an interdisciplinary specialty now generally called Human Factors Engineering. Some of the major milestones in the Human Factors Engineering Field are listed in Table 6.

(1) Early Developments

In its early development, beginning in 1945, Human Factors Engineering was almost entirely sponsored by the Navy and Air Force, with research groups at the Navy Special Devices Center on Long Island, the Navy Research Laboratory at Anacostia, Maryland, the Navy Electronics Center at San Diego, and the Air Force Aeromedical Laboratory at Dayton, Ohio[15]. In addition to carrying out vigorous in-house programs, these laboratories supported contract research programs at a number of universities, the most important of which were at Johns Hopkins University and Tufts College[16]. Efforts were directed at finding the best match, or interface, between men and the machines which they operate, ride in as passengers, or maintain. Rather quickly the research led to improved design principles that

TABLE 6. MAJOR MILESTONES IN HUMAN FACTORS ENGINEERING

Year	Event	Sponsor
1945-46	Establishment of Human Factors Engineering research groups in US Navy and Air Force[15]	Govt/Mil
1949	Handbook of Human Engineering Data[16]. Navy Special Devices Center and Tufts University	Govt/Mil
1950	USAF Anthropometric (body size) survey[19].	Govt/Mil
1951	Air Navigation and Development Board Report on Human Engineering for an Effective Air-Navigation and Traffic Control System[17].	Govt/Mil & Civ
1951-55	Human Engineering studies of air traffic control (Ohio State University for USAF)	Govt/Mil
1952	Establishment of US Army Human Factors Engineering group (Aberdeen, Maryland)	Govt/Mil
1954	Beginning of rapid expansion of Human Factors Engineering into industry[18]. See Figure 1	Priv Sect
1957	Formation of Human Factors Society	All
1958	Establishment of Human Factors Engineering research group in FAA (Atlantic City)	Govt/Civ
1963	Human Engineering Guide to Equipment Design[20] (Prepared by US Navy, Air Force, and Army)	Govt/Mil

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were particularly applicable to aircraft cockpits and passenger compartments, and to ground equipment such as combat information centers and air traffic control systems. Among the improvements in cockpit equipment that resulted from these efforts were shape coding of cockpit controls, cockpit standardization within major aircraft types, design of engine instruments for easier check reading and a replacement for the three-pointer altimeter which was shown to constitute a serious accident hazard because of misreading errors. The benefits of Human Factors Engineering showed up in reduced pilot error accidents, more efficient ground operations, and crew stations and seats that were better matched to human body sizes.

During this early period the Air Force supported a series of studies in Air Traffic Control at the Ohio State University[17]. These studies were aimed at problems of traffic density and all-weather operation with an eye to both accident prevention and increased efficiency. Improved methods were developed for displaying and processing information and for communicating between air and ground.

By 1952 a few major companies, particularly Bell Telephone and Hughes Aircraft, began employing Human Factors specialists. During the ensuing years, and particularly after 1954, the growth trend for Human Factors Engineering Groups[18] employed by industry accelerated rapidly as shown in Figure 1. Most of these groups were in the aerospace industry, working on both military and civil aviation systems.

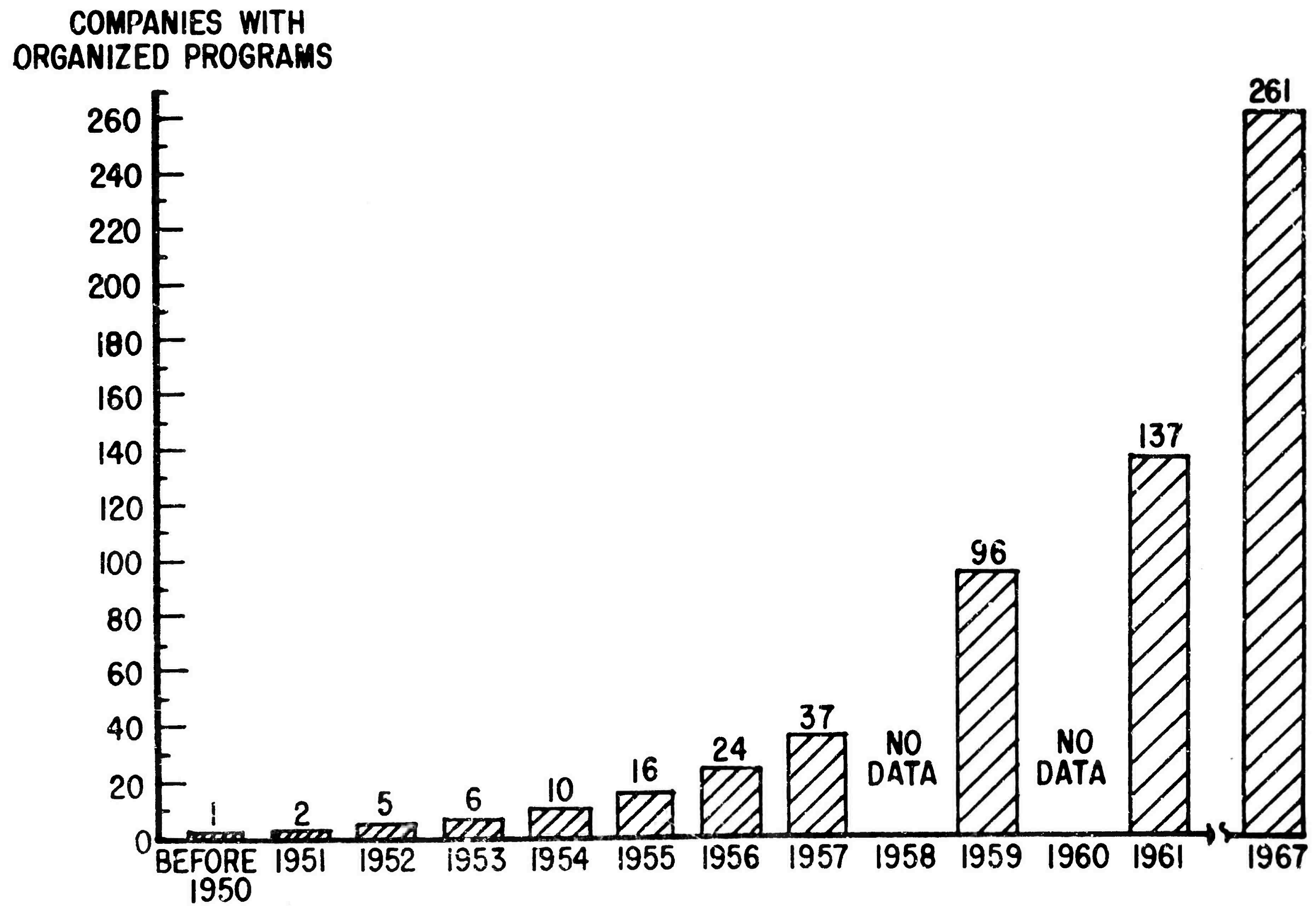
There are two rather different categories of interface dealt with by human factors engineering. The first and larger of these is the interface for both directions of information flow between people and machines, and between the people themselves. This is the information interface. There is also the physical interface involving factors such as body size, movement, and strength.

The Information Interface

A large amount of military human factors engineering R&D has been applied to the design of instrument presentations, instrument lighting, controls and control systems, radar scopes, warning devices, maps, charts and other devices used for man/machine information exchange. Although much of this effort has been focused on cockpit equipment, this research has also been applied to ground equipment, such as that used in combat information and air traffic control centers.

The Physical Interface

A problem considerably smaller in scope, but very important, is the physical fit between man and equipment. This problem is complicated by the great variation among people in such important physical characteristics as weight, stature, sitting height, reach distance, and



GROWTH TREND – INDUSTRIAL HUMAN FACTORS ACTIVITY (FROM KRAFT, 1961)

Figure 1

strength. Yet, all, or very nearly all body sizes must be accommodated. Thus, the design of seats, work stations, and control devices, as well as the location of instruments and controls in the work station, must be guided by human statistical data.

A major anthropometric survey to obtain statistical data on over 137 human physical dimensions was initiated by the USAF in 1950[19], and obtained measurements on over 4,000 men. These data have been widely used by the aircraft and other industries for physical sizing and arranging of spaces occupied by people. This basic data pool was supplemented in the period of 1967-1968 with additional surveys by the US Army, Navy and Air Force. This latest Air Force survey included 1,900 women.

(2) Flow of Technology

In the period from 1945 to 1955 Human Factors R&D was limited almost entirely to four Navy and Air Force laboratories, and a corresponding number of university groups working on military contracts. While the number of military laboratory groups has changed very little since that time, a large expansion into industry lagged about 10 years behind the initial military build-up, as shown in Figure 1. An FAA laboratory counterpart of the military laboratory groups was set up in 1958.

The technical advancements and specific contributions to civil aviation from R&D on the man/machine interface are often hard to identify. From the research output came design data, principles, and criteria, which have been disseminated through research reports, handbooks and design guides. Some major handbooks[16,20] are listed in Table 6. Data from these handbooks have been widely used in military specifications and internal company documents. These, in turn, are used by designers of hardware for both military and civil aviation.

(3) Civil Aviation Benefits

The data on man/machine interface has been widely applied to civil aviation equipment by the manufacturers of such equipment. Optimization of the man/machine interface has improved safety and economy by the reduction of human errors and by generally improved efficiency of air and ground operations.

Much of the cockpit equipment used in civil aviation, such as flight and engine instruments, instrument lighting, control devices, and warning systems, is derived from equipment developed for military aircraft, and to which human factors data have been applied.

(4) Subsequent Developments

During the period since about 1957 there have been some noteworthy changes of direction in military Human Factors Engineering. As manned space flight became a national goal many of the research programs were diverted from aircraft applications to problems of manned space vehicles. As a consequence, many important contributions were made in the areas of space cabin design, zero and lunar gravity operations, and extra-vehicular operations. Even before the shift of interest to manned space flight, considerable Human Factors effort had been diverted from aircraft to ballistic missiles, and to the human problems of ground handling, maintaining, and launching missiles.

In the past several years, however, there has been a general return to aircraft problems as the focus of military efforts in Human Factors Engineering. This occurred after the rapid build-ups in the missile and space programs came to an end. In this return to aircraft problems, a large number of technical areas are receiving attention. Among these are heads-up displays, anti-collision displays, predictor display applications, digital computer interface equipment, and new control concepts.

(5) Costs

The total annual cost of military R&D in all areas of Human Factors Engineering is estimated to be about $6,000K.

f. PILOT TRAINING AND TRAINING SIMULATOR DEVELOPMENT

Since the early days of powered flight, pilots and pilot instructors have looked for suitable means for teaching and practicing the skills and procedures of flying. Since the majority of these skills were general for all flying, regardless of the aircraft, the same general training methods were used by commercial, private, and military organizations. Large numbers of pilots trained by the military were later hired by the civilian sector and given further transition training. Because of the hazards and high cost of training in actual flight, there has always been interest in providing as much as possible of the training and maintenance of flying proficiency in ground-based simulators. The major milestones in training simulator development are listed in Table 7.

(1) Early Development

The pioneering effort that led to the flight simulator as we know it today was the Link Trainer, developed by E. A. Link, for private pilot training and was placed into operation approximately 1929.

TABLE 7. MAJOR MILESTONES IN TRAINING SIMULATOR DEVELOPMENT

Year	Event	Sponsor
1929	Invention of Link Trainer (Ed Link)	Priv Sect
1941-45	Mass use of Link Trainer in WW II	Govt/Mil
1945	Military pilots hired by airlines.	Priv Sect
1949	First electronic instrument trainers (Z-1 and C-1i)	Govt/Mil
1950	First electronic flight simulator (B-377)	Priv Sect
1958	First television visual simulation (DALTO)	Priv Sect & Govt/Mil
1960	First digital computer flight simulator[22] (F9F and F-100)	Govt/Mil
1962	Visual Simulation (SMK-23)	Govt/Mil
1965	Improved visual simulation for airlines.	Priv Sect

It was originally used as a demonstrator to attract "fledglings" into the flying hobby. It very quickly became useful in pilot selection and for training in control coordination. Since early flying was by the seat of the pants only, the first trainer was a visual contact trainer that used the walls of the room as an attitude reference. Since the Link Trainer represented an attempt by a player piano company to develop a new product line, during the depression years, the design of the Link Trainer was based upon many techniques that were the hall marks of the player piano, such as a pneumatic bellows and an ingenious air motor.

From the U S Army's experience in flying the mail, the need for instrument flying and more scientific procedures in control and navigation became evident. So, during the '30's the Link Trainer, which was developed for private pilot training, was used in developing the basic flight instruments and instrument flying procedures that were used by the Army Air Corps in the accelerated pilot training programs during World War II. Although the "Link" became a part of the life of thousands of Department of Defense pilots, its limitations restricted its use for some of the more advanced combat procedures. There was a need to simulate not only the basic flight instruments, but also all other cockpit instruments and controls. Also, due to their mechanical nature, mechanical systems generated the display indications for a given set of conditions only (such as straight and level cruise) and as the display varied from the nominal, the indications departed from reality.

Experiences in developing electromechanical models of the early Link Trainer led to the development of the original electronic instrument trainer. Specifications were developed by the Air Force in approximately 1946. The first elementary system was developed by Dr. R. C. Dehmel about the same time. Working for the Curtiss-Wright Corporation he developed a general simulator of a piston engine aircraft (Z-1) which was delivered to the Air Force in 1949, and a simulator of a general jet aircraft (C-11) was developed by the Link Company and delivered at the same time.

Experiences in the development of the Z-1 and C-11 instrument trainers indicated the feasibility of developing a complete aircraft simulator. The original specifications were developed by the Air Force about 1948. The program was delayed due to funding problems. Based upon these experiences the Pan American Airlines contracted for a Boeing 377 Simulator with the Curtiss Wright Corporation, which was in operation in 1950. A contract was awarded by the Air Force for a B-50 Flight Simulator which was in operation in 1951. Success in the development of these flight simulators then led to the development of additional simulators for the C-97, C-124, B-36, B-47. The

Air Force also developed the first D C analog computer flight simulator system[21] in 1956 (YF-102). These D C analog computers then became standard for all DoD and commercial simulators for the next 5-7 years.

With the rapid development of high speed digital computers, many studies were conducted, by Government and commercial firms, to determine the feasibility of using digital computer techniques to solve, in real time, the six degree of freedom flight equations for simulation. The first program to succeed in this area was sponsored jointly by the Air Force and the Navy and developed by the University of Pennsylvania. The simulator developed by this effort[22] had two cockpits (F-100 and F9F), either one of which could be operated from the central computer (UDOFT). This simulator was placed into operation in 1960, and demonstrated the feasibility of real-time digital simulation, and presented the first true mathematical simulation of a complete aircraft, with the reprogramming flexibility of a general purpose digital computer. From this beginning, a whole new industry developed for the market in medium size, real-time digital computers, and all flight simulators developed in the next decade were based upon their operation.

Since the flight simulator proved its capability as a cockpit instrument procedures trainer, the users looked to further expansion of its capabilities into the visual flight regime[23]. Numerous attempts by the Government and industry, such as a television device built by DALTO, in 1958, had very limited application. The first partially successful visual simulation system was then developed by the Air Force and placed into operation in 1962 (SMK-23). Although this visual system did not meet all of the visual requirements, it did provide a means for using Commands to evaluate the value of such a device in a pilot training program and to determine in more specific detail, their requirements for visual simulation. The basic techniques employed in the SMK-23 visual system were a moving model, an optical probe, television pick-up and television projection.

(2) Flow of Technology

Some indication of the flow of technology is apparent in Table 7. As each new advance was made, and appeared in a specific simulator, the new technology was available to all simulator manufacturers, and promptly applied to future simulators. The time lags in this flow of technology appear to have been very short.

(3) Civil Aviation Benefits

Through the hiring of highly trained military pilots, commercial aviation has been spared much of the high cost of pilot

training. Much of the transition training of pilots to specific aircraft and maintenance of flying proficiency, has benefited greatly from the simulator technology developed largely through military support of R&D by simulator manufacturers.

(4) Subsequent Developments

Since the initial production of the SMK-23 visual simulation device by the Department of Defense, improved designs of these basic techniques were developed by industry and built into an operating system for the commercial airlines, and placed into operation approximately 1965. This combination of digital simulation and a visual capability has been adopted by the airlines as the primary training facility for their jumbo jet series of aircraft (1970).

Based upon the airlines' success in utilizing visual and instrument simulation in transition training, the Air Force initiated the development of an Advanced Simulation System for research in the area of Undergraduate Pilot Training[24, 25]. Also, based upon these experiences, the Air Force is initiating a program to add visual simulation to the existing C-5 and C-141 flight simulators. Also, this same technology for flight simulation has been used by NASA in both aircraft and space vehicle simulators.

(5) Costs

The annual cost of military R&D on simulation techniques for flight training is estimated to be about $1,000K.

g. CRASH PROTECTION AND IMPACT TOLERANCE CRITERIA

The extreme hazards of aircraft crash environments were identified during man's earliest attempts to achieve free flight with winged vehicles. The first attempts to provide protection against crash included the incorporation of a simple restraint harness. Only minor progress was made in this area until the post World War II period. Military research and development activities of this period were incorporated into the civil aviation technology in the late 1950 period. On-going and future military research that applies to civil aviation includes efforts to define human impact exposure limits, develop crash resistant structures, develop impact attenuation systems and improve personnel restraint. Milestones are shown in Table 8.

(1) Early Development

Only minor attempts were made to improve crash safety prior to World War II. Injury and mortality rates were accepted as an

TABLE 8. MILESTONES IN CRASH PROTECTION AND IMPACT TOLERANCE CRITERIA

Year	Event	Sponsor
1940-45	Incorporation of shoulder harness	Govt/Mil
1945	Combination of inertia reel with shoulder harness	Govt/Mil
1950	Requirement for rear-facing passenger seats	Govt/Mil
1949-57	Stapp's[27, 28] work on impact tolerance limits	Govt/Mil
1950-58	Eiband's summary of human tolerance criteria[26]	Govt/Civ
1955	Utilization of Daisy Horizontal Decelerator	Govt/Mil & Civ
1968	Air Bag Restraint Evaluation for DoT by USAF	Govt/Civ

inherent part of aviation. The most significant military contributions to the technology that supports civil aviation crash survival research and development were made in the post World War II period and the following decade. These contributions have been documented by Martin Eiband[26] of the NACA in a report entitled, "Human Tolerance to Rapidly Applied Acceleration", dated November 1958. Specific noteworthy military efforts are: The impact tolerance study of Stapp[27,28] of the USAF during the period of 1949 to 1957, the work of Bierman[29,30] of the USN on protection principles and impact tolerance during the period of 1946 to 1947, and the research of Shaw and Savely[31] of the USAF during 1946 to 1951 on the human response to impact and the development of personal protective equipment. These works were assembled by Eiband to provide design guidance for civil aviation design applications. The impact exposure limit guidance that is contained within this report is based almost entirely on the work of Stapp. Eiband's summary of the influence of protection systems upon voluntary tolerance is based on the works of Stapp, Bierman and Ruff. Information about the aircraft crash environment has been provided by the FAA through full-scale crash tests of large transport aircraft conducted during 1964-1965.

A major military contribution to the areas of human impact tolerance, crash protection, crashworthiness of seats, etc., was the development, maintenance and operation of manrated horizontal and vertical acceleration and deceleration devices for this research. After the original tests by Stapp and others on high-speed sleds built for aerodynamic and hardware testing, special deceleration devices for animal and human tests were developed. The Daisy Decelerator (1955) at Holloman AFB, New Mexico, is an example of such a device. Since its completion it has been used continuously for crash protection research and testing.

(2) Flow of Technology

The contributions that have been made by military research and development in this area have been provided to civil aviation in two ways. First, within the numerous technical reports that have been prepared by the military research and development organizations. Second, within more recent times there have been a series of government agency aircraft seating conferences to encourage the exchange of data in this area.

(3) Civil Aviation Benefits

The civil aviation efforts conducted to improve crash survival have been almost entirely reliant upon the human impact research programs conducted by the U. S. Air Force and Navy aeromedical organizations. The civil aviation crash survival design effort has also made extensive use of the research conducted on the dynamics of aircraft and seat structures by the U. S. Navy and Army. On-going and future efforts of the military services to develop improved restraint systems, seat structures, ground egress systems, and crash attenuation devices will continue to provide valuable information to the civil aviation crash safety program.

(4) Subsequent Development

Information gained from the review of operational accident reports of both military and civil aviation have provided important data on the overall efficacy of crew protection techniques. This information has caused a continuous refinement of equipment design as well as a source of validation for estimates of human impact exposure limits.

(5) Costs

The annual cost of military R&D on crash protection and impact tolerance is estimated to be about $500K.

h. HUMAN TOLERANCE TO VIBRATION AND BUFFETING

Since the early days of aviation it has been known that vibration and turbulence affect the comfort, performance and safety of aircrew and passengers in aircraft. Vibrations are produced by the engine and airframe dynamics, by adverse weather, by clear-air turbulence, and by aircraft maneuvers and flight at low altitude. Research to explore the effects of vibration on people had its major beginnings about 1930, and from this research have come standards for vibration and ride quality, to improve both safety and comfort, that are available for use by the entire transportation industry. The major milestones in the achievement of these standards are listed in Table 9.

(1) Early Developments

The first significant research on the effects of vibration on people was carried out in Germany, by Reiher and Meister[32], beginning about 1931. Their work derived threshold values for perception, comfort and discomfort, with reference to vibration in homes, factories, and terrestrial vehicles. Similar studies were conducted by several

TABLE 9. MAJOR MILESTONES IN THE DEVELOPMENT OF HUMAN VIBRATION TOLERANCE CRITERIA FOR MANNED AIRCRAFT

Year	Event	Sponsor
1931-35	Early criteria developed for vibration thresholds of perception, comfort, and discomfort (Reiher & Meister in Germany)[32]	Priv Sect
1948	Summary and description of comfort criteria (Goldman, US Navy)[33]	Govt/Mil
1955	Development of vibration tolerance criteria (Getline, USAF)[34]	Govt/Mil
1958-62	Early research on effects of vibration on human performance (Simons, Schmitz and Hornick)[35,36]	Govt/Mil
1958	Extension of human tolerance criteria into painful and physically intolerable range (Ziegenrucker and Magid, USAF)[37]	Govt/Mil
1960	Updated and refined review of effects of vibration on human beings (Goldman and von Gierke, U. S. Navy and USAF)[38]	Govt/Mil
1963	Development of aircraft ride quality criteria (Notess, USAF)[39]	Govt/Mil
1964-70	Development of vibration standard by international standards organization technical committee	All
1970	Development of military vibration standard (Mil Std 1472A)	Govt/Mil

others in Europe and the United States before World War II. In 1948 the work toward development of standards for human exposure to vibration was considerably advanced by Goldman[33], of the US Navy, through publication of a summary of vibration data up to that time. In 1954 the USAF established a comprehensive program on the effects of vibration and turbulence on aircrew safety and performance, and developed unique laboratory facilities for simulating and studying low altitude high speed flight vibrations in the laboratory. One of the early German workers, Coermann, came to the U.S. after World War II and conducted studies on human vibration tolerance under this program. He also conducted some of the earliest studies of vibration effects on visual acuity and tracking capability. In 1955, Getline[34], established the first military standards for vibration goals in aircraft with reference to crew tolerance. The USN developed in 1955 a buffeting capability on its human centrifuge which was used for the following 15 years for pilot performance studies under vibration superimposed on sustained G and clear-air turbulence studies for the FAA. During the period 1958-62, pioneering studies of human performance during vibration were carried out by Simons and Schmitz[35] and Hornick[36]. The motivation for their work was the improvement of seats for trucks, tractors, and other terrestrial vehicles. Measurements extending vibration tolerance into the painful and intolerable range were made in 1959 by Ziegenrueker and Magid[37] of the USAF. In 1960, a comprehensive review of all vibration research was prepared by Goldman and von Gierke[38], a joint USN-USAF effort. Notess[39] in 1963 published ride quality standards for aircraft. Soon thereafter work was started under USAF leadership to update military vibration exposure standards and to develop national and international standards for use in aviation as well as other industries. Some of these developments are listed in Table 9.

(2) Flow of Technology

As is demonstrated by the above developmental history, the technology efforts began with civilian studies related to ground transportation and vibration in buildings. Subsequently the military and civilian sectors carried on concurrent efforts with a free and rapid interchange of technology. Military emphasis on human tolerance, crew member performance, physiological effects and psychophysiological effects under vibration was blended very advantageously with civilian emphasis on passenger comfort/discomfort, long term, low level vibration acceptance and sensory perception under vibration. Standards resulting from this technology are equally available and applicable to civilian or military applications.

(3) Civil Aviation Benefits

The establishment of criteria for human comfort,

efficient performance and safety have and will contribute to engineering and design of aircraft, power plants and controls to optimize these aspects of flight for aircrews and passengers. These criteria are also used in the design of automatic gustload alleviation equipment, vibration isolation equipment, and the design of displays, employed to improve comfort and safety of modern high speed aircraft.

(4) Subsequent Developments

Active and passive vibration isolation devices have been designed and employed by civilian and military sectors concurrently with the advances in understanding of vibration effects on humans. Recently automatic servo controlled gust load alleviation and stabilization devices have been designed for modern, high speed, flexible airframe aircraft to damp out effects of turbulence and smooth the ride.

SECTION III

CURRENT AND PLANNED R&D EFFORTS

Except in the area of cabin pressurization, there are military programs continuing in all of the areas of research and development already discussed. In some of these areas there are programs being carried out jointly with DoT/FAA and NASA, or other government agencies. Many of the already known technical problems for HF/AM have been only partially solved, and require continuing effort. Other new problems become known only as engineering advances open up new avenues for aviation progress, or as major system development plans are formalized. As this happens existing research capabilities are reoriented, or new ones are organized. Described below are those continuing HF/AM R&D efforts which appear to offer the most significant benefits to civil aviation.

a. NOISE EFFECTS ON CIVILIAN POPULATIONS

Large numbers of military personnel and their air base neighbors will continue to be exposed to aircraft noise. Smaller numbers will be exposed to sonic booms. Thus, there is a continuing need for military R&D on noise and its effects on people, and all three military departments have active programs. Some of these programs are joint efforts between DoD, DoT/FAA, and NASA. In a few instances there is also participation by the Departments of Labor (DoL), and Health, Education and Welfare (HEW). The Committee on Hearing and Bioacoustics of the National Research Council serves as a clearing house for research on the effects of noise. Specific research programs are planned to fit in with objectives of an Interagency Noise Abatement Program.

There are active and continuing programs in the following areas:

(1) Revision of operational procedures by aircrews to reduce the noise exposure on the ground

(2) Further improvement of indices of noise exposure, i.e., importance of background noise, time of day, amount of prior exposure, and the like, in unacceptability of aircraft noise

(3) Further study of compatible land use and its implementation to provide clear administrative guidance and practical alternative programs

(4) Revision and updating of the land use planning guidelines to be consistent with contemporary aircraft and airport utilization

(5) Assessment of impact of new noise sources on personnel and communities, i.e., C-5A, 747, rotary wing aircraft, VSTOL and VTOL aircraft, and possibly a supersonic transport

(6) Assessment of long term biological and subjective effects of continuous and impulsive type exposures on personnel and populations, including sleep interference

(7) Continued development of hearing protective devices for all noise environments

(8) Immediate and long term effects of noise and of noise plus other stressors, on mental and motor performance

(9) Continued assessment of loudness and acceptability of sonic boom exposures, including sleep interference, relative to a commercial supersonic transport

b. AVIATION MEDICINE FOR CIVIL AVIATION

There is continuing military research in Aviation Medicine which will benefit clinical medical practice in civil aviation. Five important areas of research, and the military departments conducting such research, are as follows:

(1) Drug effects on crew performance (Tranquilizers, sedatives, stimulants, and antibiotics (USN, USAF)

(2) Time zone shift (Desynchronization) effects from long-range flights (USAF)

(3) Flight disorientation (Vertigo) from inner ear stimulation (USN, USAF)

(4) Revision and validation of physical standards (especially with respect to significance of degenerative disease associated with aging) (USN, USA, USAF)

(5) Development of physical standards based on individual physiologic status as opposed to chronological age (USN, USAF)

c. TOXICITY OF AVIATION MATERIALS

The Air Force toxicology research and testing program will be continued, and will provide data on new materials being considered for use in aviation. Funding for a portion of this program will be supplied by FAA.

d. MAN/MACHINE INTERFACE FOR AIR AND GROUND SYSTEMS

Within DoD all three departments maintain active Human Factors engineering and contract programs. The scope of these efforts is very wide ranging, and focused on many different types of interface problems. From these efforts, however, there are possible advancements of the following kinds:

(1) Still further reductions in aircraft accidents caused by human error, either in the cockpit or on the ground.

(2) Improved "heads up" displays permitting the pilot to read critical flight data while maintaining outside vision during landings.

(3) New concepts of vehicle control suitable for VTOL aircraft.

(4) Predictor displays giving the pilot and air traffic controller better anticipation of aircraft future positions.

e. SIMULATION FOR FLIGHT TRAINING

Current R&D is centered around development of still further improvements in visual simulation of what the pilot sees through his windshield. Efforts are being devoted to achievement of higher resolution, larger angular coverage, larger geographical coverage, and computer generation and storage of the visual images. Another aspect that continues to receive attention is that of motion simulation. There are not only unresolved questions of how best to provide such motion, but how to provide motion cues which will be most realistic. A third problem is the measurement of pilot proficiency in flying the simulator, as a means of predicting pilot proficiency in actual flight. Different approaches to these problem areas are being followed by the USAF, and by the Army and Navy at the Naval Training Devices Center at Orlando, Florida.

f. CRASH PROTECTION AND IMPACT TOLERANCE

The current impact research efforts that are being conducted by the military aeromedical laboratories to define human exposure limits continuously provide new data for civil aviation applications. Ongoing USAF work with animal subjects, at the Daisy Decelerator at Holloman Air Force Base, has been designed to study the effects of aircraft crash environments. Other research is being conducted by the Navy, Army and Air Force to provide protection during helicopter impact.

The USAF has been supporting the Department of Transportation by conducting a series of impact tests of air bag restraint systems. These tests have employed dummy, animal, and human subjects in an experimental effort designed to evaluate the merits of this relatively new protective concept. This concept is currently being considered for application in commercial passenger transport aircraft.

Another series of experiments is currently being planned by the USAF with NASA-Ames to evaluate a new energy absorption passenger seat using experimental techniques developed by the Air Force. The tests will employ a new physical analog of the whole body response characteristics of the human body to load the seat more accurately during impact tests.

SECTION IV

SUMMARY

In all the technical areas of Human Factors/Aviation Medicine, R&D by the military sector has clearly made outstanding contributions to civil aviation. Broadly, these contributions have been in terms of flight safety, health, operating efficiency, pollution control and community relations.

The operating conditions for military aviation are generally more severe than for civil aviation. In the process of solving the human problems for the more severe military conditions, Human Factors/Aviation Medicine has provided many satisfactory solutions for civil aviation.

The flow of technology has been predominantly from military R&D to the civilian sector. But there have also been significant instances, as in the case of the Link Trainer, where civilian commercial efforts stimulated military use and further technological advances. In many areas of technological advancement, such as cabin pressurization and training simulators, there appears to have been rapid transfer of new capabilities.

An assessment of current trends and look to the future does not indicate a divergence in the human problem areas facing military and civil aviation. Thus the contributions from military R&D can be expected to continue at a high level.

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APPENDIX 6

AIR VEHICLE TECHNOLOGY

JOINT DoD-NASA-DoT
"R&D CONTRIBUTIONS TO AVIATION PROGRESS
(RADCAP) STUDY

HOWARD A. MAGRATH
USAF/AFSC (AFFDL/FY)
PANEL CHAIRMAN

AUGUST 1972

APPENDIX 6

AIR VEHICLE TECHNOLOGY

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SECTION I

INTRODUCTION

In 1799, Sir George Cayley clearly saw that the key to man's successful flight depended upon the separation of the lifting and propelling functions in the design of aircraft. Air Vehicle Technology likewise embraces the design of the aircraft as a lifting machine independently of propulsion developments.

Modern Air Vehicle Technology began in September 1901, when the Wright brothers started their wind tunnel experiments in Dayton, Ohio. By 1925, engineering development had transformed the Kittyhawk into airplanes for war, and into airplanes for cargo, for passengers and for sportsmen. By this time, the Atlantic Ocean had been crossed by the Navy's famed NC-4 and the airplane had established itself in its dual role - a machine for war and a machine for commerce. Its two strong sponsors were governments and the civilian entrepreneurs. In the United States, there has been a continuous interchange of engineering information between these two groups.

This Appendix deals with this interchange and dual sponsorship in terms of significant advances in the development of the airplane since 1925, and in terms of the current and planned research and development programs in the government on the one hand, and in the civil industry on the other.

The significant advances and their times of occurrence are shown on Figure 1. The significant advances are intended to indicate an initial technical breakthrough in the state of the art of airplane design without which the airplane as we know it today would probably not yet have been developed; and from which derivative developments ensued, the technology of which is in use today and shows promise of further developments for the future. An example is the landing gear. In 1921, a retractable landing gear was incorporated on the Air Corps XPS-1 experimental airplanes. This was followed by the oleo strut, multiple wheels, the tricycle gear, shimmy dampers, anti-skid, and high flotation. And now being investigated is the air cushion landing system. The significant advances that were chosen appear to meet the above criteria - no claim is made that these are a unique set or are the only ones that could have been selected.

This Appendix primarily covers military R&D. The related programs of NASA and DoT are outlined but do not have the depth of coverage as to the military programs.

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SIGNIFICANT ADVANCES SINCE 1925

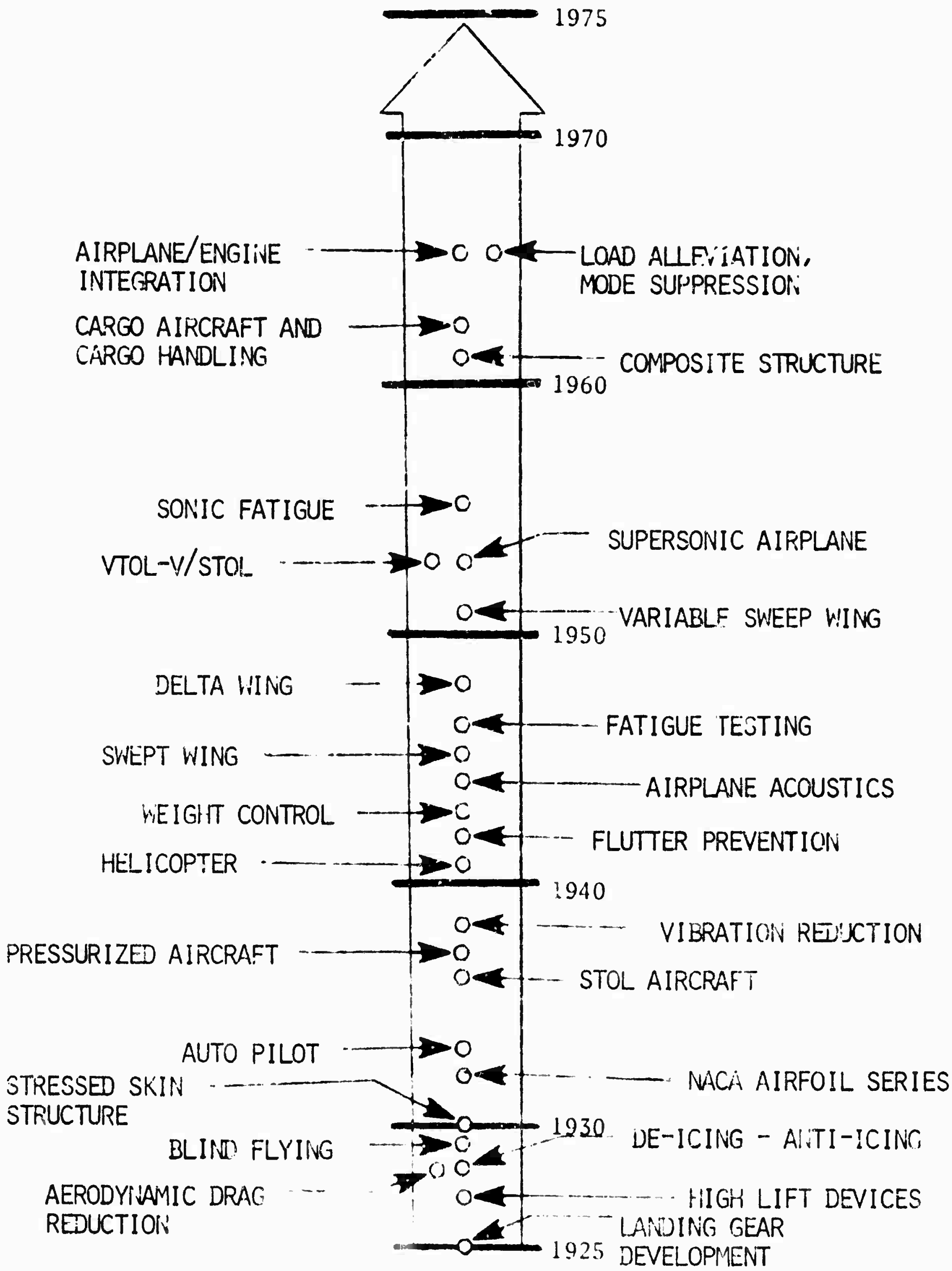

FIGURE 1

SECTION II

SIGNIFICANT ADVANCES SINCE 1925

Air Vehicle Technology requires the knowledge and skills related not only to the principles of flight, but also to structural, mechanical and electrical engineering, chemistry, physics, and psychology. The chief characteristics of this technology are its interdisciplinary nature and the very broad spectrum of its activity. For this reason, the significant advances are presented by grouping them according to the disciplines that make up the Air Vehicle Technology. This grouping is shown in Figure 2.

The events within each group are presented so as to preserve as far as possible the chronology of events. The groups arranged as subsections are: (A) Flight Mechanics, (B) Structures, (C) Flight Control, (D) Vehicle Dynamics, (E) Vehicle Equipment. In addition to these five disciplines, there is added (F) Aircraft Developments to indicate the technology of the special aircraft: Short Take-off and Landing aircraft (STOL); Helicopters; and Vertical Take-off and Landing (VTOL) and Vertical and Short Take-off and Landing aircraft (V/STOL). Also included in this subsection is that class of aircraft that has the closest relation to the civil airliner - the cargo airplanes and their associated cargo handling systems.

Finally, there is included in this Section an account of the development of Design Handbooks because these are an important means of communication between the R&D establishments and the airplane constructor and an important channel through which technology is formally transferred.

The significant advances cover the time period from 1925 to about 1965. Research and development for the time from about 1965 to the present are presented in Section III of this Appendix beginning on page 145.

SECTION II-A
FLIGHT MECHANICS

In this subsection of Significant Advances Since 1925, eight advances have been chosen to illustrate the flow of R&D progress in Flight Mechanics. The eight advances are: (1) High Lift Devices, (2) Aerodynamic Drag Reduction, (3) NACA Airfoil Series, (4) Swept Wing, (5) Delta Wing, (6) Variable Sweep Wing, (7) Supersonic Airplane, and (8) Aircraft-Propulsion System Integration.

A. FLIGHT MECHANICS

High Lift Devices	1927
Drag Reduction	1928
NACA Airfoil Series	1932
Swept Wing	1945
Delta Wing	1948
Variable Sweep Wing	19[illegible]1
Supersonic Airplane	1953
Airplane/Inlet	1965

B. STRUCTURES

Stressed Skin	1930
Weight Control	1943
Fatigue Testing	1946
Fibrous Composites	1961

C. FLIGHT CONTROL

Blind Flying	1929
Auto Pilot	1933
Load Alleviation	1965

D. VEHICLE DYNAMICS

Vibration Reduction	1938
Flutter Prevention	1942
Airplane Acoustics	1944
Sonic Fatigue	1955

E. VEHICLE EQUIPMENT

Landing Gear	1925
De-icing - Anti-icing	1928
Pressurized Aircraft	1937

F. AIRCRAFT DEVELOPMENTS

STOL Aircraft	1936
Helicopter	1941
VTOL and V/STOL*	1953
Cargo Handling	1962

G. DESIGN HANDBOOKS

*V/STOL - Vertical and Short Take-off and Landing Aircraft.

FIGURE 2

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A-1. High Lift Devices

(1) Early Development

The simplest form of flap, a hinged section of the wing trailing edge that can be deflected downward, was first used on a British S.E.-4 biplane in 1914. However, the effectiveness of this design, especially on a biplane, was so small that it was never widely employed. The concept of the leading edge slot (Ref. 1) and its action in increasing the lift of an airfoil, was developed independently by the Germans and British (Lachmann, Handley Page, and Mader) in the 1919 - 1920 time period. This concept was crucial to the further development of the flap, for a slot or gap between the flap leading edge and the wing greatly increased the flap efficiency. Nevertheless, little use was made of the slotted wing or slotted flaps during the 1920's. The Air Service conducted a study of slotted airfoils with and without flaps at McCook Field in 1926. The first general use of wing leading edge slots was as stall prevention devices on military aircraft of that era.

Two other flap concepts were also developed during the 1920's. The split flap had only the lower surface of the wing trailing edge hinged for downward deflection, while the upper surface remained fixed. The Fowler Flap invented and built as a private venture in 1927, moved rearward as it deflected downward so that the wing area was increased. The simpler split flap was first used on civil airplanes, the Northrop Gamma and the Lockheed Orion in 1932 (Ref. 2) and the Douglas DC-1 in 1933. It was 1937 before the Fowler Flap was first used on the Lockheed 14 twin-engine airliner (Ref. 2). Military use of the split flap started in 1936 on the Boeing P-26C (Ref. 3). The split flap enjoyed more widespread usage during the 1930's. Military use of the Fowler type flap commenced about 1941 with the Lockheed Hudson Model 14 and the P-38 fighter (Ref. 4).

(2) Flow of Technology

Application of slotted wing and flap technology of the 1920's was limited to aircraft designed by Handley Page or Lachmann until they sold their patents. Because this sale was to governments only, the first general applications were to military aircraft in the U.S. and Great Britain. However, the manufacturers of military aircraft were also building commercial airliners, so advances in flap technology found simultaneous application in both fields. The basic research work performed by NACA, and the Technical Development Programs of the Air Corps were well documented in technical reports which received wide distribution to all companies engaged in aircraft design.

(3) Civil Aviation Benefits

Civil aviation places a high priority on passenger comfort and safety. Therefore, the critical take-off and landing phases of aircraft operation have received much attention. Flap systems developed originally for military aircraft have been extensively refined and improved for civil application. Benefits have been achieved not only in increased efficiency, safety and comfort, but also in shorter take-off and landing requirements. All modern aircraft employ some type of flap system, often in combination with leading edge slats.

(4) Subsequent Development

As the aircraft designers came to realize that improved flap systems would allow higher wing loadings and greater aerodynamic efficiencies, they began development of the slotted flap (Ref. 5). Much wind tunnel testing was done by NACA and the Air Corps on all types of flap systems. In 1938, the Douglas DC-4 became the first U.S. commercial airliner to incroporate a slotted flap design (Ref. 6). Development of the double-slotted flap by Douglas was motivated by military requirements for transport and combat aircraft in 1940. Perhaps the most well known combat airplane employing the double slotted flap was the Douglas A-26. Similar flap systems were used on the C-74 military transport and the DC-6 and DC-7 airliners, and later on the DC-8 jet transport. Boeing went one step further and developed a triply slotted flap system for their 727 jet transport.

An important development following the general adoption of slotted flap systems has been the development of various leading edge devices. Although the leading edge slot (or movable slat which forms a slotted flap ahead of the airfoil when extended) was originally used to prevent stalling of military and certain high performance civil aircraft, its widespread use on civil transports did not come about until the swept-back wing planform was generally adopted. This type of wing is susceptible to a leading edge stall phenomena. Leading edge flaps and slots increase the maximum lift and eliminate pitch-up tendencies near maximum lift. Many combinations of leading edge devices are used on swept wing aircraft, but the Kruger flap, a simple concept consisting of a flap hinged along its forward edge on the underside of the wing near the leading edge, is often employed on the wing near the fuselage. It swings down and forward to effectively increase the wing leading edge radius and prevent airflow separation.

The quest for lifting performance better than that obtained from mechanical flaps led to the study of boundary layer control systems (BLC). High lift boundary layer control research began after World War II, with attempts to adapt the German developed jet pump BLC system to U.S. aircraft. The first program of this type was the application of the Arado 232 jet pump scheme to an Air Force C-123 cargo airplane in January 1955 (Ref. 7). Projected maximum lift

performance was demonstrated, but control problems were encountered during slow speed flight. While this research on transport aircraft was being conducted, high lift BLC investigation on fighter aircraft was also proceeding.

In 1952, the Navy installed a high speed blowing flap system proposed by Attinello (Ref. 8) in an F9F-4 Panther aircraft with good results. In 1954, an improved blowing flap system of this same type was installed by the Navy on production T2V-1 Starfire airplanes. The most successful Navy BLC application to date is the F-4 program which started with first flight in May 1958 and has carried through over 17,000 production deliveries. Air Force fighter high lift BLC experiments include the F-86 and F-104 aircraft. The Air Force YF-104A prototype flew successfully for the first time in February 1954 with production deliveries starting in January 1958. The transition of high lift BLC to civil aviation will take place on transport category aircraft and in this area NACA/NASA has been the driving factor. Research programs such as the modification of a Boeing 707 to the jet flap configuration for flight testing, and numerous large scale wind tunnel tests of BLC high lift devices have assisted in developing the technology required to proceed with the development of STOL transport aircraft.

(5) R&D Costs

A cumulative of estimated expenditures over the past 35 years is 40 million dollars.

A-2. Aerodynamic Drag Reduction

(1) Early Development

About 1928, those working in the aeronautical field became increasingly concerned about drag in an effort to increase speed. Airplanes like the P-26, which was the last of the wire braced fighters, were replaced with cleaner airplanes. Metal monocoque structures were introduced, external bracing was eliminated, cockpits were inclosed, wing fillets were added and landing gears were made retractable. Particularly effective were the low drag radial engine cowlings developed by NACA (Ref. 9) for which the Collier Trophy was awarded to NACA for the year 1929. About the same time, extensive work was done on Reynolds Number effects in aerodynamic investigations. Later, tests were conducted to determine the effects of protuberances, scoops, steps in the sheet metal skins, gaps, fairing of external antennae. In 1932, J. Nikuradse (Ref. 10) found that skin friction drag became a constant above a certain (critical) Reynolds Number depending inversely upon the grain roughness of the surfaces.

With the advent of higher performance propeller airplanes during World War II, aircraft began to experience compressibility effects. Investigations were then conducted on thinner wings and low-drag airfoils. The P-51 Mustang incoporated a low-drag, laminar flow airfoil in order to improve its high speed performance; as a result, it was an outstanding fighter of World War II.

Use of jet engines in aircraft permitted still higher airspeeds and even more severe compressibility problems. This triggered investigations into still thinner wings, swept wings (Ref.11) and wings with lower aspect ratios, in an attempt to avoid the high local Mach numbers that resulted in high drag as well as control problems. After World War II, it was found that Bussemann, in Germany, had outlined the advantages of wing sweep in 1935.

In 1941, a method for predicting the equivalent parasite drag area for aircraft was developed (Ref. 12). This permitted a more accurate prediction of performance, thus highlighting the importance of aerodynamic excellence. Airplanes like the F-86 in the early 1950's and the B-47 in the mid 1950's, which incorporated thin swept wings, proved the wing technology required for the commercial transports such as the 707 and DC-8. The experience gained with canards and delta wings on airplanes such as the B-70, provided experience and data for supersonic flight. This experience in aerodynamic design as regards swept and delta planforms is available if supersonic or hypersonic flight becomes economically feasible as a commercial transport method.

(2) Flow of Technology

The flow of technology was transferred directly and rapidly from NASA, and the Military Services, to industry and consequently to civil aviation. This transfer was made not only in the form of formal reports, memoranda, meetings, symposia, journals, etc., but more directly, through the testing of models in government wind tunnels.

Prior to World War II, NACA was the principal agency in the United States doing systematic aerodynamic testing and their expertise was sought out. During World War II, due to the close coupling between NACA, the Military Services, and industry, technology was transferred on a daily basis, and there was no lag between R&D and applications. Finally, after World War II, the military and NACA/NASA continued to develop and transfer technology to industry through the development and testing of families of advanced, high speed aircraft.

(3) Civil Aviation Benefits

Civil aviation has been and will continue to be a prime recipient of DoD developed aerodynamic technology. In developing the best possible fighter and bomber aircraft, DoD funds are used to develop advanced aerodynamic technology which is directly applicable to the civil fleet, at no cost to the civil fleet. A prime example was the proof of swept wing technology on the F-86 and B-47, coupled with the propulsion technology from the F-100 and B-52, which enabled an economical, safe jet transport (Boeing 707) to be developed.

(4) Subsequent Development

In 1952, Whitcomb (Ref. 10) found through systematic experiments that the wave drag of a wing-body combination when approaching M=1 is primarily dependent on the axial distribution of cross-sectional area normal to the airstream. This principle has since been referred to as the "Area Rule". The first airplanes to use the area rule were the Grumman F-11F-1 and Convair YF-102A, both of which first flew in 1954. The transonic area rule principle was expanded by Jones (Ref. 11) in 1956 to be applicable at supersonic Mach numbers.

During the late 1940's and 1950's, the importance of inlet, exit and afterbody design was recognized by NASA and the Air Force and appropriate investigative research programs were conducted. In 1963, during the development of the F-111 airplane, it became apparent that inlet and nozzle/afterbody research and development had not progressed to the point where good low drag designs could be accomplished with confidence for multi-mission operations. As a result, both NASA and the Air Force undertook extensive inlet, exit and afterbody design programs. This work is discussed in A-8 of this subsection.

The most recent and most significant development from the standpoint of the civil airlines is that of the supercritical wing program by Dr. Whitcomb, and the NASA Advanced Transport Technology Program. Through the coupling of a blended fuselage-supercritical wing, and optimized area ruling, a large transport aircraft having low drag can be developed which will cruise at or near Mach 1. Efficient flight in this regime can result in safe, comfortable, transportation near the speed of sound, with greatly alleviated sonic boom effects. Again, the flight proof of this concept is being borne by DoD and NASA through the Navy T-2C, USAF TACT F-111, and NASA SCW F8 Programs, and represents a potential technology transfer directly applicable to civil airlines.

(5) R&D Costs

Recent expenditures are approximately 2.2 million dollars. The cumulative DoD expenditure over the past forty years is estimated at 50 million dollars.

A-3. NACA Airfoil Series

(1) Early Development

Early development (1920) of wing sections was almost entirely empirical. Gradual development of wing theory isolated the wing-section problem from the effects of planforms, and a more systematic approach developed. Wind tunnel tests made at Goettingen during World War I contributed much to the development of modern airfoils. Up to World War II, most sections in general usage were more or less direct extensions of the work performed at Goettingen. During this time period, outstanding work was performed by NACA in investigations and development of systematic families of wing sections. The cambered sections of these families were obtained by combining a mean line and a thickness distribution. When the NACA four digit wing sections were derived, it was found that the thickness distributions of the more efficient wing sections (Goettingen 398, Clark Y) were nearly the same when the mean camber line was removed and they were reduced to the same maximum thickness. Consequently, the four digit series thickness envelope closely resembled these, while the mean camber line was formed from two parabolic arcs. The results of the four digit series tests showed that the maximum lift coefficient increased as the position of maximum camber was moved forward. To derive an airfoil with higher lift, a new series of mean lines was developed, which was the NACA five digit series. This series was reported upon in 1935 in NACA Report No. 537 (Ref. 15).

During this same time period (1930's), systematic investigations were beginning with respect to improved high lift for landing and take-off. Pinkerton, in 1930, (Ref. 16) calculated the variation of flap lift with section lift coefficient and flap deflection. The development of flaps followed rapidly with split, slotted, double-slotted, and triple-slotted flaps. In parallel with these investigations was the development of leading edge slats, and the first systematic study of slats was reported on by Weick and Shortal in 1932 (Ref. 17). Leading edge flaps were investigated more recently (during World War II). Although not as powerful as trailing edge flaps, they may be used full span, without interference with lateral control devices. This subject has been covered more fully in A-1, "High Lift Devices", in this subsection.

(2) Flow of Technology

The above technology was transferred through formal reports, memorandums, IAS (now AIAA) symposia, journals, and technical papers to all government and industry agencies connected with the aerospace industry especially during World War II due to the close association of NACA and the aircraft industry.

(3) Civil Aviation Benefits

The civil aviation fleet has benefited to a great extent from the development of the NACA airfoil series. Primarily through the emphasis on military fighters and bombers just before and during World War II, the military aircraft were utilized as test beds to prove the technology which was later used in commercial and general civil aircraft. Most airfoil sections and high lift landing and take-off devices are based on NACA developed airfoil systems.

(4) Subsequent Development

Returning to the development of airfoil sections, the NACA 1 series represented the first attempt to develop families having desired pressure distributions, and are the first low-drag, high critical-speed wing sections. Prior to 1939, development of laminar boundary layer airfoils was hampered by lack of adequate theory. This was the first family where such a design was possible, and these are characterized by small leading edge radii and large trailing edge angles. Although it gave extremely low drag near the design lift coefficient for a smooth airfoil, the drag became unduly large at high lift coefficients. The NACA 6 series was then develcped to provide for extensive laminar flow, however, flexibility was provided for off-design lift coefficients. Final airfoil family development evolved the NACA 7 series (Ref. 18). These airfoils are characterized by a greater extent of possible laminar flow on the lower surface than on the upper surface. These sections permit low pitching moment coefficients with moderately high design lift coefficients, at the expense of some reduction in maximum lift and critical Mach number.

Following the development of the above discussed conventional airfoil families, NASA has continued development of advanced airfoils, the most noteworthy being the supercritical airfoil developed by Dr. Whitcomb, NASA Langley. This airfoil is designed to have a high drag divergence Mach number and to be essentially shockless under cruise conditions. This effort is continuing with application to both military and civilian aircraft. The USAF is developing the supercritical wing technology for improved combat maneuvering. NASA is furthering development of the Advanced Transport Technology Program, which applies supercritical wing technology to advanced civil transports.

(5) R&D Costs

Essentially, no DoD funds were expended in the NACA/NASA airfoil series development. However, airfoils of other advanced types are being developed by DoD. Over the past 15 years, the cumulative expenditure is estimated at 10 million dollars.

A-4. Swept Wing

(1) Early Development

Theoretical work in Germany by Bussemann and Betz (1935 - 1939) on swept wing theory was followed by experimental work by Lippisch in Germany, Hill in England, and Jones (Ref. 19) in the United States. The first swept wing aircraft using sweep for high speed flight was the ME-163 (1939). The undesirable handling qualities of sweep (Ref. 20) delayed use of swept wings until transfer of German technology at the end of World War II.

(2) Flow of Technology

In November 1944, North American proposed a jet fighter design for the Air Force which was to become the F-86. The first wind tunnel tests showed the straight wing concept could not reach the desired 600 mph. At this point, North American Aviation designers became interested in German wind tunnel reports on swept wings. German research showed that sweeping the wing reduced drag but introduced undesirable stability effects. North American had worked on the pioneer swept wing airplane, the XP-55, in 1943, and knew of the difficulties first hand. The F-86 was redesigned for a swept wing, and this changed the airplane from a mediocre fighter into a great one (Ref. 21). In 1946, the U.S. Navy experimented with a Bell P-63 modified with a 35° swept wing. Renamed the L-39, the aircraft was used to gather information on the effects of wing sweep associated with carrier operations (Ref.22). The Boeing B-47 (Ref. 23) provided the aerodynamic technology and basic design information necessary for efficient jet transports. The combination of high aspect ratio and sweep employed for the B-47 developed the confidence necessary for the design of the B-52. The high performance jet engines developed for the B-52 enabled the extension of the technology for application to the C-135 and 707 transport aircraft.

(3) Civil Aviation Benefits

The introduction of the swept wing allowed the introduction of the pure jet airliner into the civil fleet. The swept wing

enables cruise Mach numbers greater than 0.9 and combined with supercritical airfoils will permit development of the transonic transport.

(4) Subsequent Development

Development has been limited to improving airfoil sections for swept wing applications and in improved fuselage wing blending. The development of the variable sweep wing for the F-111 provided new technology which may contribute to supersonic transport development in the future (see section A-6, page 18).

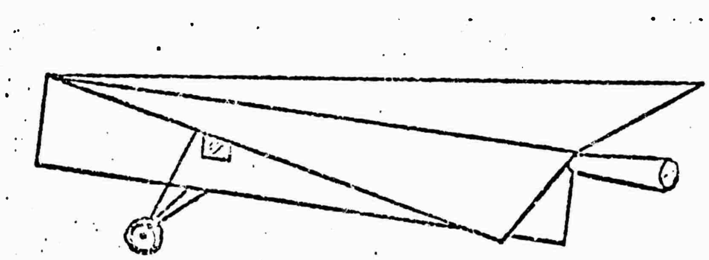
(5) R&D Costs

Over the past 25 years the DoD cumulative expenditure is estimated at 5 million dollars.

A-5. Delta Wing

(1) Early Development

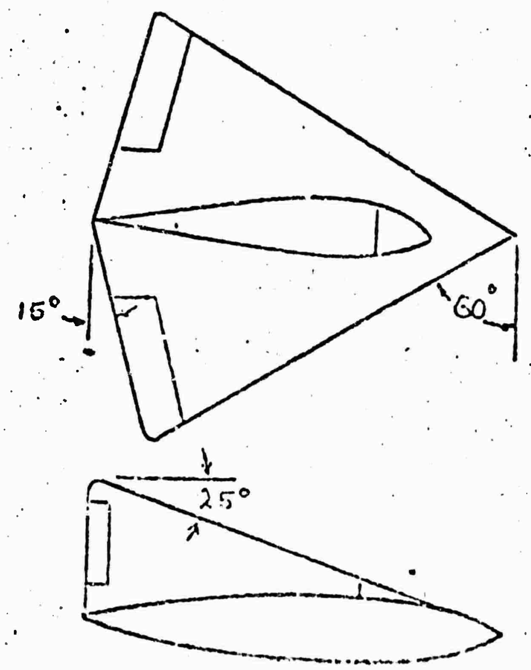
The earliest recorded evidence of this unique wing dates back to 1867, when the concept was patented by Butler and Edwards (Ref. 24). Their machine, as shown below, if built, would have been powered by either steam jets or a propeller.



Little is recorded on the delta wing until the 1930's. Dr. Alexander Lippisch flew a delta wing-flying wing aircraft in Germany during 1931 and in 1934, Payen flew his Pa 100 Flechair. Scroggs began experimenting with a delta wing similar to the Butler and Edwards concept, but powered by a reciprocating engine (Ref. 25). Prior to World War II, it was generally felt that the main advantage of the delta wing concept lay in the reduction of the aircraft fuselage size, with a subsequent improvement in overall vehicle performance. The practical limit of this concept was a flying wing which was pursued by the U.S., France, and Germany. With the coming of World War II and the increase in aircraft speed, new benefits of the

delta wing became apparent. These included a delay in the transonic drag rise, curbing the rapid movement in center of pressure at transonic speeds, and providing a wing with extreme structural simplicity and rigidity as well as a high strength to weight ratio.

Germany recognized these benefits and began wind tunnel studies of delta wing shapes earlier in the war, with the classic results of Lange and Wacke, first published in 1943, still in use today (Ref. 26). Dr. Alexander Lippisch began a serious evaluation of the delta wing shape for possible application to an advanced fighter-interceptor, and was ready to start flight tests on several prototypes at the close of the war. One of these, the DM-1 (Ref. 27) was transported to the U.S. where it underwent extensive wind tunnel testing by NACA, with the results published in NACA RM L6K20 and RM L7F16. A sketch of this configuration, which served as an ancestor to many of today's delta wing fighters, is shown below.



(2) Flow of Technology

The technology of the delta wing existed for some time as a subject of personal interest, for such individuals as Dr. Alexander Lippisch, and as an area of intellectual study before it was

considered a practical airplane design. It was the desire for supersonic flight that first brought the delta wing into prominence. Prototypes were under construction in Germany during the last days of World War II. During the late 1940's, both the United States and Great Britain built and flew experimental jet powered designs. In the U.S., the Air Force's Convair XF-92A first flew on 18 September 1948 (Ref. 28). In subsequent years the Soviets, France, and Sweden also found the delta wing to be useful in military aircraft. All five countries have continued to explore and use delta wing designs up to the present. In the early 1950's, Great Britain built several large subsonic delta wing bombers after they satisfactorily solved the low speed - high angle stability problem. The design was selected because it allowed a lighter structure with less drag, since the fuselage was very small. In 1955, a commercial version of the AVRO 689 Vulcan was proposed for use in trans-Atlantic flights. It could have accommodated 130 passengers and traveled 600 mph., but the proposal was never carried out. An excellent application to vertical take-off and landing was undertaken in the Convair XFY-1 and the Ryan X-13 experimental airplanes. Transition from horizontal to vertical flight was demonstrated with both designs. In the late 1950's and early 1960's, the U.S. and Russia led a vigorous program in delta wing vehicles with Great Britain and France contributing a couple of concepts. The B-58 and B-70 demonstrated for the U.S. the technology for large supersonic aircraft. The impetus for the development of the technology in all nations has been basically to fulfill military needs. With the realization of a commercial supersonic transport, the delta wing has found unique application to the civilian economy. The chronology of the delta wing is given in Table I. The chronology of typical delta wing aircraft is shown in Figure 3.

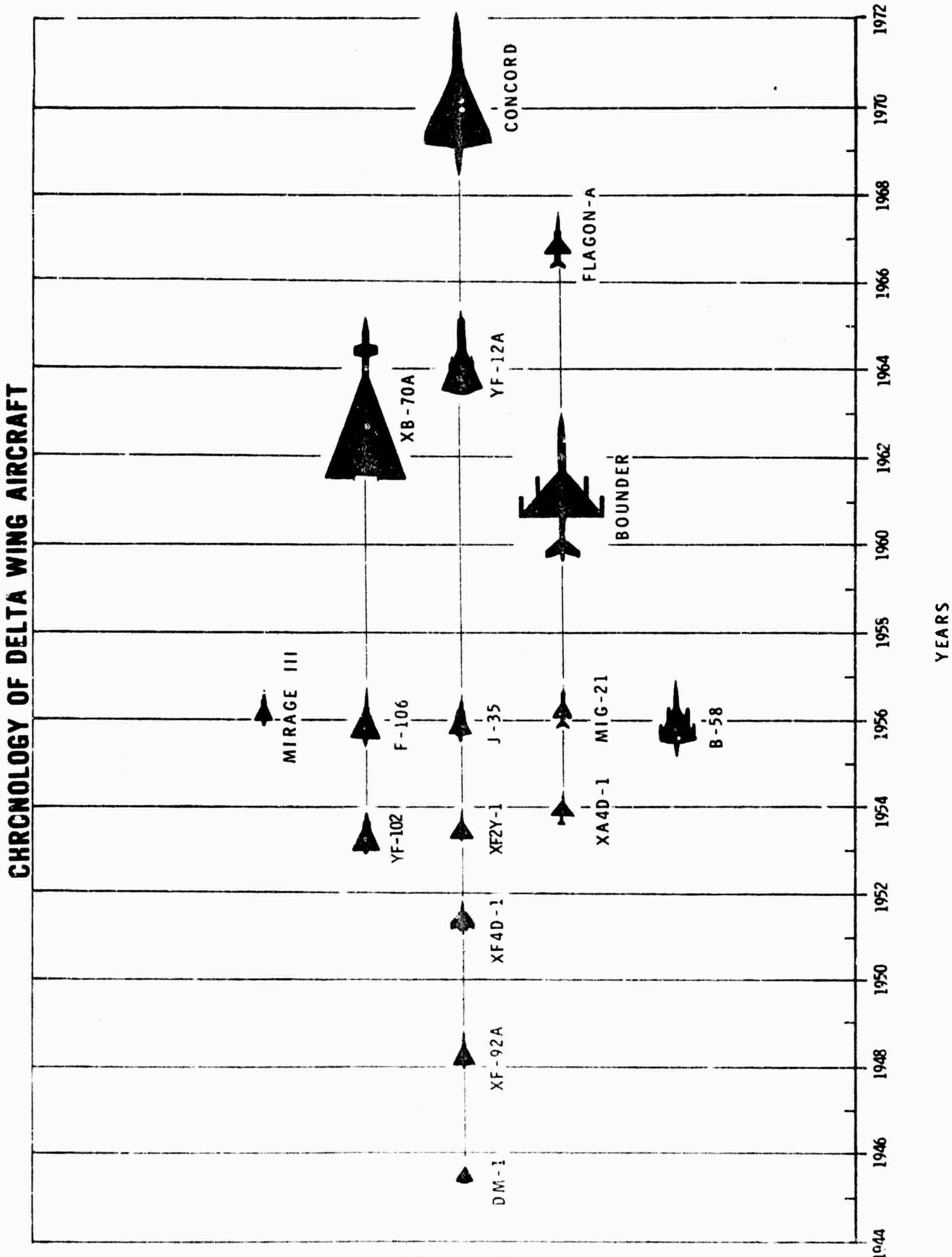
(3) Civil Aviation Benefits

Until the appearance of the supersonic transport, the conventional, moderately swept wing had proven more than satisfactory for the commercial jet transport market. To operate profitably at supersonic speeds a new airfoil section with considerably reduced thickness-chord ratio was required. Because the large chord of the delta wing provides a low value of thickness to chord ratio, the delta wing was a natural selection for the supersonic transport configuration. Competitive designs using variable geometry were also evaluated, but in the end, the supersonic transport designs were based on a delta, double delta, or related planform. The delta wing has also found a unique application in the light airplane field. Several successful designs were demonstrated during the mid 1960's.

TABLE I

CHRONOLOGY OF DELTA WING TECHNOLOGY

1867	Patent for Delta Wing, Stream-jet Propelled Airplane by Butler and Edwards (USA).
1931	Alexander Lippisch Delta I Glider (Germany).
1934	N.R. Payen: PA-100 Flechair (France).
1937	Lippisch Delta IV
1943	Lange-Wacke Experimental Report (Germany).
1945	Lippisch Delta VI Turbojet Fighter, PA-11, PA-12, PA-13 Fighter Designs (Germany).
	Lippisch DM-1 (Germany).
	A. Lippisch Discussions with T. vonKarman, H. Dryden.
1946	R.T. Jones Theory of Delta Wings (USA).
1948	Convair XF-92A, First Jet Powered Delta (USA).
1949	AVRO Type 707 (Great Britain).
1950	Bulton Paul P. 111 (Great Britain).
1951	Douglas XF4D-1 Skyray (USA).
	Fairey F.D. 1 (Great Britain).
	SAAB 210 Draken (Sweden).
	Gloster Javelin (Great Britain).
1952	AVRO Vulcan (Great Britain).
	Bulton Paul P. 120 (Great Britain).
1953	Convair YF2Y-1 Sea Dart (USA).
	Convair F-102 (USA).
1954	1402 Gerfaut (France).
	Payen PA-49 (France).
	Douglas Skyhawk A-4D (USA).
	Convair XFY-1 (USA).
	Fairey F.D.2 (Great Britain).
1955	Dassault Mirage (France).
1956	Ryan Vertijet X-13 (USA).
	Convair F-106 (USA).
	Convair B-58 (USA).
	MIG-21 (USSR).
1960	Bounder (USSR).
1964	TSR-2 (Great Britain).
	B-70 (USA).
	YF-12 (USA).
1965	F-111 (USA).
1968	SAAB-37 Viggen (Sweden).
	Supersonic Transport (USSR).
1969	Supersonic Transport (France/Great Britain).



CHRONOLOGY OF DELTA WING AIRCRAFT
DM-1
XF-92A
XF4D-1
YF-102
XF2Y-1
XA4D-1
MIRAGE III
F-106
J-35
MIG-21
B-58
BOUNDER
XB-70A
YF-12A
FLAGON-A
CONCORD
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
YEARS

FIGURE 5

(4) Subsequent Development

Development efforts follow the particular application requirements which are currently under consideration. The United States is continuing to explore Space Shuttle designs. The USA, and most likely the USSR, are studying delta wing designs for their advanced interceptor and fighter projects. Until recently the United States supersonic transport design efforts were centered on delta wing types. At any time in the future when a civil aircraft is required for supersonic flight or extreme maneuvering capabilities at high speeds, the technology from experimental and military aircraft is ready for immediate application.

(5) R&D Costs

The funding information available is very sketchy and lumps all research together, hence, the cost noted here is only a rough estimate. The amount in the neighborhood of 368 million dollars has been spent over the past twenty years. This cost is included in the expenditure quoted under Supersonic Airplane.

A-6. Variable Sweep Wing

(1) Early Development

One of the earliest forms of variable wing geometry experimented with was that of the telescoping wing. Designed by Ivan Makhonine, this design was first flown on August 11, 1931, near Paris, France. The initial flight trials were so successful that the French government granted Makhonine one million francs to continue his work (Ref. 29).

Another early concept that employed a completely different principle was developed in the Soviet Union just before World War II. In an attempt to combine the extreme maneuverability of the biplane with the speed of the monoplane, an airplane with a retracting lower wing was developed. Built by Nikitin-Sevchenko, the IS-1 featured a lower wing hinged at the root and a spanwise chord station, so that the inboard wing panel folded vertically against the fuselage and the outer wing panel folded against the lower surface of the upper wing. Flown late in 1940, no significant problems were encountered, but the performance gain was not sufficient to justify the increased complexity (Ref. 30).

During the latter stages of World War II, high speed aircraft began to encounter the transonic drag rise, necessitating some form of swept wing to produce acceptable drag levels. In Germany, experiments were underway with both forward and rearward swept wings, and although successful in alleviating transonic drag, they had adverse effects in other speed regimes. In an attempt to produce an airplane with good characteristics at all speeds, the Germans conceived an unusual variable geometry scheme in which the entire wing rotated, the starboard wing sweeping back and the port wing forward. This concept was to be employed on the Blohm & Voss P-202 (Ref.31). Although the aircraft was never built, the concept was of sufficient interest to be evaluated by NASA in the early 1960's (Ref. 32), however, it had also been originally examined by NASA in the mid 1940's.

After World War II, the inability of a single geometric configuration to provide good performance over the rapidly increasing flight envelope renewed the interest in variable geometry. By this time the concept of variable sweep was accepted as the most advantageous form of variable geometry, but the principle had yet to be demonstrated experimentally. The first aircraft to employ variable sweep, the Bell X-5 and the Grumman XF10F-1, both flew in the early 1950's in the United States (Ref. 23). One of the major problems was rearward movement of the aerodynamic center when the wings were swept. However, the solution of translating the wing roots forward as the wings swept back posed many mechanical problems. Although aerodynamically acceptable, the complexity of the approach prevented its practical application.

Following the completion of the X-5 research program, numerous studies were conducted to find a satisfactory solution to the aero-mechanical sweep problem, and after extensive testing, a modified system was proposed by NASA. The wing pivot points were moved outward from the fuselage centerline and only the outer wing panels were movable. With a substantial portion of the gross wing area fixed, an acceptable aerodynamic center travel was realized without having to translate the wing (Ref. 33).

Consideration has also been given to variable camber and twist. The means of accomplishing this in a practical form has not yet been developed.

(2) Flow of Technology

The single, outboard pivot approach yielded most of the advantages of the earlier variable sweep concepts, and its simplicity paved the way for its application to military systems. During the 1950's and early 1960's, a number of experimental programs were

conducted applying variable sweep technology. Once a sufficient technology base had been established, variable geometry was incorporated in the F-111. Additional variable sweep aircraft employing these principles have since been developed in the United States, France, and the Soviet Union. International designs, such as the Panavia Multi-Role Combat Aircraft (MRCA), are also under development by various European countries.

(3) Civil Aviation Benefits

Civil aviation will reap benefits from such variable geometry devices as the variable sweep wing. Variable geometry affords the only practical method of de-coupling the supersonic-subsonic speed regimes, and therefore, was extensively evaluated throughout the supersonic transport competition. At high speeds, the variable sweep wing in its maximum sweep condition provides most of the aerodynamic advantages of the delta wing, while at low speeds the high aspect ratio provides good take-off and landing characteristics. Although none of the final supersonic transport configurations employed variable geometry, the main reasons for its elimination were mechanical rather than aerodynamic.

Another variable geometry proposal which has possible civilian application consists of the folding wing-tip concept. This approach would find its most likely application in the light airplane field.

(4) Subsequent Development

The development of the variable geometry wing, described as the most significant advance in airframe development in a decade, is continuing in the United States, the Soviet Union, and several European countries. It is being applied to air superiority fighters, strike and bomber aircraft.

To be sure, its development has not been without some setbacks, but it should not be judged too critically in light of its infancy. As military aircraft continue to gain experience with this concept, the remaining aeromechanical problems will be solved, and when the next generation civilian aircraft demands high speed operation, a sound technology base for variable sweep will be available for application.

(5) R&D Costs

Although accurate data concerning the cost of research and development programs in variable sweep geometry concepts is not readily available, general expenditure information puts the amount in the neighborhood of 180 million dollars spent over the past fourteen years.

A-7. Supersonic Airplane

(1) Early Development

No appreciable attention was given to possible flight beyond M=1 prior to World War II and as a result, there was an improper understanding of the impact of Mach number on vehicle flight. The clean fighter designs of World War II originally exhibited a series of unusual phenomena, e.g., control reversal, when pulling high speed maneuvers during combat which resulted in a number of accidents which appeared at the time to be unexplainable. These accidents stimulated activity within the technical community to gain insight into the causes and the corrective action which might be taken. As a result, the Air Force and NACA conducted extensive research programs in aerodynamics and vehicle configuration characteristics which led to the first reasonable understanding of Mach number effects and dispelled the Sonic Barrier Myth.

During the post war period and the era of the subsonic jet fighters, such as the F-86, transonic flight was commonplace in diving maneuvers and extensive work was carried on in flight through the transonic and supersonic regimes. From this work evolved a series of X aircraft developed for research flight testing in these speed regimes.

The X-1, piloted by Captain Charles Yeager, was the first of such vehicles that made the first level flight run at speeds greater than Mach 1 on October 14, 1947. This aircraft was used in flight experiments up to M=1.4 to obtain data on stability, buffeting, reaction control technology and aerodynamic phenomena such as boundary layer transition and aerodynamic interference. The X-3 was the first test vehicle powered by a turbojet engine and configured for experiments on design and materials technology in the supersonic speed regime. The design was derived as a joint Air Force, Navy, and NACA development at the time. Unfortunately, flight expectations were not achieved. The X-5 research vehicle was designed to conduct research on the benefits to be gained through variable sweep wing configurations.

The Korean air war impressed the Air Force with the capabilities of the MIG-15, and in response to the performance capabilities it displayed, efforts were undertaken on an improved program for the F-86. This led to the development of the Century series of supersonic fighters the first of which to achieve straight and level supersonic flight was the YF-100A on May 25, 1953. By the end of the 1950's, Mach 2 flight was commonplace, and the technology was applied to bomber class aircraft in the development of the B-58

(2) Flow of Technology

Within the U.S., technology is transferred through joint DOD/NASA efforts during system development. At times this transition is often subtle and reflects itself in terms of experience and knowledge gained from joint efforts being applied to civil programs. Supersonic transport development, being the only civil application of supersonic aircraft technology, was more formally transferred through a joint USAF/NASA/FAA XB-70 Flight Research Program. This flight test program was directed toward supersonic aircraft technology. It originated in 1966 and continued through 1969. Figure 4 shows a list of the technology items and disciplines considered.

(3) Civil Aviation Benefits

The military needs have been the primary forcing function in the development of the technology for supersonic aircraft, large and small. The application to civil aviation has been limited and must await development of requirements in the civil sector. As noted above, the technology has been developed.

(4) Subsequent Development

In 1957, the F-101 set three new speed and distance records. This was followed in the early 1960's by the record flight of the B-58, and later a non-stop flight from Carswell AFB to Paris in record time. Other speed and distance records were established by U.S. aircraft. The impressive times of these supersonic flights were instrumental in the decision to pursue supersonic transport development in both the western nations as well as the USSR, and this decision resulted in 1965 in maintaining operation of the XB-70 as a research flight test vehicle.

The mid 1960's brought forth the YF-12, the SR-71, and the MIG-23 all of which achieved Mach 3 flight.

The development of technology for such vehicles continues in the NASA and DoD. The fundamental technology is being developed by this team. Its eventual application to military needs is evident. The application to civil aircraft development is dependent on a number of factors but not really the availability of technology.

(5) R&D Costs

No direct correlation of cost is readily available which will provide an accurate estimate of the costs for fundamental research and the research associated with specific aircraft

F 299

TEST OBJECTIVES
JOINT USAF/NASA/FAA XB-70 FLIGHT RESEARCH PROGRAM

A. AERODYNAMICS

1. Lift/Drag
2. Component Drag
3. Boundary Layer Transition
4. Boundary Layer Noise
5. Stability and Control and Handling Qualities
6. General Performance

B. SYSTEMS

1. Engine-Inlet Matching
2. Hydraulics
3. Air Crew Display
4. Electrical
5. Flight Controls
6. Stability Augmentation
6a. Elastic Mode Control
7. Engine Control

C. STRUCTURES

1. Materials
2. General Flight Loads
3. Flight Loads Technology
4. Landing Loads
5. Dynamic Loads

D. PROPULSION

1. Engine Performance
2. Inlet - Duct Performance
3. Fuels and Lubricants

E. FLIGHT ENVIRONMENTAL FACTORS

1. Sonic Boom
2. Near/Far Field Noise
3. Thermal
4. Meteorological
5. Biomedical

FIGURE 4

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development. However, it is estimated that such research costs have been a total of 1.49 billion dollars over the past 25 years, about 60 million dollars per year.

A-8. Aircraft Propulsion System Integration

(1) Early Development

The development of air induction systems is closely associated with the development of the jet engine and jet powered aircraft. Although the principles of jet propulsion can be traced back as far as the Hero's aeolipile of the first century, and a gas turbine engine was patented in England in 1791, the development of the first practical systems did not evolve until the late 1930's and early 1940's. Prior to World War II, extensive development work in engines and aircraft was being accomplished in England, Germany, and Italy. Whittle is credited with the development of the first gas turbine engine, while Campini appears to have produced the first jet powered aircraft (1935) and by 1940 had designed an aircraft with an inlet that could operate above the speed of sound.

U.S. interest in jet aircraft was almost non-existent prior to World War II. In 1938, the Air Corps at Wright Field began a small program to develop the gas turbine. The Air Force and General Electric were also developing the turbosupercharger in this time period. In 1939, NACA was charged with basic research into turbojets (Ref.34), but interest was discouraged until the war. The war generated interest as well as the development of our first operational jet system, the Bell P-59A.

With the continued development of subsequent jet aircraft, the importance of the air inlet system soon became known and an increasing amount of research funds were expended. Initial subsonic jet aircraft relied upon the technology developed by NACA. The inlets were simple fixed geometry that featured blunt lip cowls that were essentially those developed by NACA for low drag piston engine cowls. With the subsequent generation of higher performance aircraft the importance of the inlet design on performance, drag and compressor face distortion became items of concern. From the beginning, aircraft capable of speeds at or above the speed of sound experienced significant problems with inlet design and inlet engine compatibility. Inlet problems on the F-80, F-86 and F-89 were experienced and with the development of the F-101 aircraft and its associated inlet development programs, the entire focus of the aircraft community was brought to bear on inlet problems. This resulted in an industry-wide meeting held at Wright-Patterson AFB

in June 1955, "Joint Industry-Government Meeting on Inlet Engine Compatibility", which concentrated on the problems of inlet design, inlet distortion and inlet/engine compatibility.

Following this, as higher supersonic speeds were reached, increasing emphasis on inlet development was sponsored by both NACA/NASA and the DoD, primarily in its system development programs. The increase in emphasis on the space program during the early 1960's reduced active NASA support in the area of airbreathing propulsion systems. Military interest in this time period covered the flight regime up to hypersonic speeds but was at a generally low level of concern.

The development of the F-111 weapon system, once again directed the research efforts of industry, NASA and the DoD toward the problems of inlet design and engine compatibility associated with high performance inlets and engines A second industry government meeting was held in 1969, that once again was directed at the solution of these problems. One of the principal Air Force efforts relative to inlet systems was centered within the Airframe Propulsion Subsystems Integration (APSI) which sought to identify some of the design characteristics pertinent to insuring a high performance, stable propulsion system. Current interest is now being focused on problems associated with designing aircraft systems with optimized installed (lowest drag) engine performance.

(2) Flow of Technology

The flow of technology has been transferred directly from the NASA and DoD to industry and subsequently to civil aviation. Prior to World War II, little effort was being expended in the United States on jet powered aircraft, and it was only as a result of DoD interest during and following the war that the development of the jet aircraft proceeded so rapidly. During this time period, propulsion system research was being performed by NASA and also industry under Air Force sponsorship. Thus, under direct government sponsorship, the technology for inlet systems was being evolved and transferred throughout the industry by means of reports, memorandums, meetings, symposia, journals, etc. It was only after successful development of subsonic and supersonic inlet systems for military aircraft that the technology became applicable to commercial aircraft systems. All current commercial subsonic aircraft employ inlet systems that have essentially been derived from the early jet aircraft developments such as the B-47 and later the B-52 turbofan and C-5 bypass turbofan system developments. The inlet systems proposed for the supersonic transport was also heavily dependent upon the inlet development of supersonic military aircraft such as the F-111, B-70 and SR-71.

(3) Civil Aviation Benefits

The civil aviation field has been and should continue to be a prime recipient of DoD sponsored aircraft-propulsion system technology. As newer and higher performing engines are developed for military aircraft, the associated technology is rapidly transferred into the commercial aircraft field with its demands for a highly efficient system.

(4) Subsequent Development

The most recent developments from the standpoint of commercial applications are the high-bypass turbofans and supersonic transports. With the development of advanced aerodynamics such as the supercritical wing, the demands placed upon the inlet and propulsion system increase and demands an inlet system of higher performance and lower drag across the flight envelope.

(5) R&D Costs

Since 1965, the DoD has expended approximately 20 million dollars in research and development efforts addressing the areas of airframe/inlet/engine compatibility and integration and in nozzle/afterbody testing.

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SECTION II-B
STRUCTURES

Military aircraft structures, because of the urgent demand for improved performance, have traditionally pioneered the development of new design concepts such as the structural application of new materials - the aluminums, titanium, columbium, fiberglass and the filamentary composites; the establishment of design data and analysis procedures, and the development of testing techniques and equipment. However, since the military design philosophy places primary emphasis on performance, i.e., speed, altitude, maneuverability, range - at the expense of other parameters such as cost and operating economy, the military vehicles generally encounter relatively more problems earlier in the life of the vehicle than do their civil counterparts. As a consequence of these factors, the commercial applications of military R&D both follow and directly benefit from military efforts.

In this subsection, four significant advances are identified that found ready acceptance by designers of civil aircraft: Stressed Skin Structure, Weight Control, Fibrous Composite Structure, and Full-Scale Fatigue Testing.

B-1. Stressed Skin Metal Airframes

(1) Early Development

As early as 1927, the reasons given by the U.S. Army's Materiel Division for not building all-metal airplanes were: (a) lack of accessibility; (b) additional weight; (c) high cost of construction; (d) corrosion of thin sheet duraluminum. The Materiel Division further stated that "Practically every airplane constructor in the United States is working on the design of metal airplanes, and much of this work is being encouraged and even financed by the Army and Navy." (Ref. 1). The cantilever monoplane wing was also in disfavor for relatively high performance airplanes due to its low torsional rigidity and resultant flutter problems (Ref. 2).

During the summers of 1931 and 1932, two twin engined, cantilever wing, all-metal, monoplane bombers were delivered to the U.S. Army's Materiel Division at Wright Field, Ohio, for competitive evaluation. One of these airplanes, the Boeing XB-901 (Y1B-9 in service test version), lost the competition but was developed into the Boeing 247 commercial transport - the first all-metal, high performance transport airplane to enter commercial service in the United States (Ref. 3). The winner of the competition, the Martin XB-907A (B-10 in production version), had a top speed of 207 mph (20 mph faster than standard Army pursuit airplanes of the time)

and won the Collier Trophy for Glenn L. Martin in 1932 (Ref. 4). Its structural arrangement was used on the four-engine Martin "Clipper" flying boats designed for Pan American Airways (Ref. 5). Both of these bombers made use of the intensive development program conducted by the Materiel Division at Wright Field into aluminum-alloy thin sheet (semi-monocoque) construction (Refs. 6 and 7).

(2) Flow of Technology

The Air Corps Materiel Division, as part of their semi-monocoque development program, designed and ground tested a series of four metal wings for a large monoplane bomber (XHB-3) design. The experimental wings were 2/5-scale models of the XHB-3 wing; three wings were of welded steel construction with fabric covering, and had two, three and multi spars. The fourth, and final, wing was a torsionally rigid cantilever wing, embodying a central box beam using corrugated aluminum-alloy sheet (17ST) for flange members and was known as the Materiel Division 55-foot cantilever all-metal wing (Ref. 8).

Captain Carl F. Greene, USAC, originated the concept for the wing and initiated the project in 1928. An extensive program of research in the field of box beams for wing structures carried out at the Materiel Division by Captain Greene and Dr. J.E. Younger, furnished data for the design and guaranteed the economy and desirability of continuing the research with the construction of the 55-foot wing. Preliminary design was conducted between September 1928 and March 1929. Static tests of the wing were carried out during October and November 1930 and the results were disseminated to industry (Ref. 9). The wing failed at station 1 on the tension flange as the jacks were being lowered with 15.5 factors (15.5 g's) on the wing (Ref. 10). Standard bomber design at the time required only design load factors of 4.5 (Ref. 11). The dramatic improvement in torsional rigidity offered by this all-metal wing is shown in Figure 5.

(3) Civil Aviation Benefits

The Materiel Division's development program into aluminum-alloy thin-sheet (semi-monocoque) construction, as well as concurrent development efforts by the Navy, NACA, and industry, culminated in the B-9 and B-10 airplanes. The significant performance advances demonstrated by these airplanes hastened the development of twin engine, all-metal, cantilever, monoplane airplanes such as the Boeing 247, Douglas DC-1/DC-2, and Lockheed "Electra" for commercial application during the 1933 and 1934 time period and made the United States the leader in commercial transport aircraft (Ref. 12).

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COMPARISON OF TORSIONAL RIGIDITIES

XHB-3 55 FT. WINGS & MAT. DIV. 55 FT. WING

(After Brown and Greene, Ref. 8)

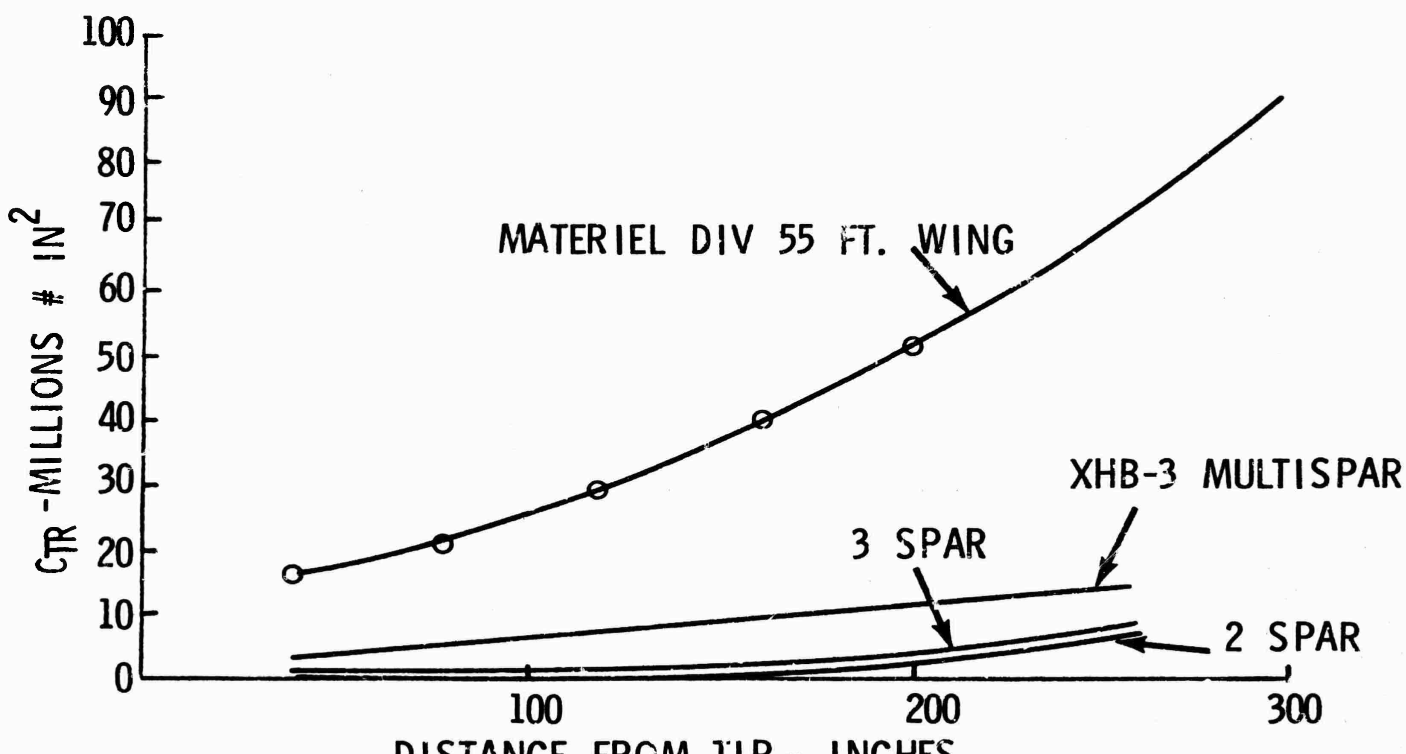

FIGURE 5

(4) Subsequent Development

The R&D on stressed skin construction for aircraft accelerated the efforts to refine and improve the efficiency of all-metal structures, develop improved methods of stress analysis, and continue research into improved materials from that time period to the present. As before, the results of military (Army, Navy, NACA, Air Force) research continue to be disseminated to industry in the form of Technical Reports, Technical Memoranda, Information Circulars, and Design Handbooks.

(5) R&D Costs

The original R&D costs for in-house developed experimental wings are unknown. It is suspected that since it was in-house, it was quite small. One of the first of two XB aircraft procured (XB-10) employing this concept cost $198,970. The continued R&D associated with improved analysis, new materials application, etc., represent an Air Force expenditure rate of approximately $1.5 million in 1955, and a continuing declining rate to the amount of $0.2 million in 1968.

B-2. Weight Control

(1) Early Development

As the airplane began to achieve recognition both as war equipment (primarily for reconnaissance) in 1914 and for commercial uses, standardization of methods and procedures for weight control became a problem. The Army Air Corps established a weight group in the early thirties to standardize weight statements and to develop calculation methods. This group in turn interfaced with the Navy.

As one would expect, airplanes were weighed on scales. In the early days mechanical scales were used. This required jacking the aircraft to permit placing of the scales under the wheels, lowering to the scales and rejacking for removal of scales. This effort was time consuming and dangerous and the scales were subject to errors from side loadings and environmental considerations. At large installations, aircraft weighing scales were built in floors so that an airplane could be towed to a scale and weighed.

The problem of determining the center of gravity position for aircraft loaded with various types of equipment and various positionings of cargo loads became tedious and time consuming. To expedite this problem, the Army Air Corps developed a load adjuster.

This is a slide rule type of device designed for each model of that aircraft to permit a weight engineer to rapidly locate the center of gravity for each loading condition.

(2) Flow of Technology

As weight engineering began to receive more recognition, standardization of calculations, weight listing and grouping became necessary. Weight engineers in government and industry began to coordinate their efforts. One evidence of this was the establishment in 1939 in Los Angeles, of the Society of Aeronautical Weight Engineers. Many weight engineers soon joined this group and on April 2, 1941, it was incorporated as a non-profit organization. The Society promoted recognition of weight control as a specialized branch of engineering, exchanged weight information for mutual benefit, combined efforts in reducing weight of purchased equipment, and promoted a better understanding among weight engineers in government and industry. Today, aircraft, missiles, space electronics, measuring and weighing equipment, land vehicle, and marine industries are represented. Many companies have profited directly from the collective experience of the world's leading experts on weight control. Many aids, such as handbooks, technical papers, and standard forms are furnished to weight engineers by the Society.

The military took the lead in developing standard forms for weight reporting such as Army-Navy AN-9102 Detail Weight Statement and AN-9103 Group Weight Statement. In 1943, Army-Navy Specification AN-W-11, Weight Control, was issued. The Air Force developed methods for calculating aircraft component and equipment weights. Industry developed their own methods.

In 1960, the Air Force set up a Weight Workshop to bring together weight engineers from industry and the Military Services so that methods, procedures, and new approaches could be discussed.

(3) Civil Aviation Benefits

The benefits gained by civilian aviation were primarily the standardization of methods and documentation, the development of weighing equipments and the development of built-in or integral systems. The engineering standardization activities were a matter of understanding and good-will among those engaged in this effort. The Air Force initiated a requirement for integral weighing during the development of the Lockheed C-130 and the Douglas C-123 cargo aircraft. However, this development was not completely incorporated until the Lockheed C-5A was developed.

(4) Subsequent Development

At the request of the Military Air Transport Service, considerable research and development efforts were expended in the fifties and sixties to provide portable platform scales with ramps, electronic cargo planning computers and electronic readout equipment for various scale systems. These were designed to be operated outdoors, no jacking was required and cargo loads could be either preplanned or planned on site. Accurate weight and center of gravity information was provided within a matter of seconds after positioning of the aircraft on the scales. Various scale sizes and capacities are now available as required. These systems are known as CPAWS, "Computer Planner Aircraft Weighing System" and MEWS, "Mobile Electronic Weighing System", and were Air Force developments initially.

Development of the multiple post strain gauge load cell permitted the use of electrical load cells mounted on jacks. These were developed by Cox and Stevens of Long Island to military specifications and were widely used by the Air Force. These weighing kits still required closed hangars and one-time jacking of the aircraft with the attendant hazard to aircraft and personnel. Versions of this equipment are still in widespread use due to comparatively low initial costs.

In the early fifties, a requirement for built-in or integral systems in the Lockheed C-130 and C-133 aircraft developed, specifically to provide more efficient and safer assault mission capabilities. No suitable approach was found until about 1955 when an in-house conceived idea was initially tested with encouraging results. The approach was to use pressure transducers tapped to the pressure within landing gear struts and converting this signal to weight and center of gravity values. Conversations with various potential manufacturers led to the development of this system by Fairchild Controls. This system is commercially used and is known as "Summed Total and Nose Gear System" (STAN) in industry. Other similar approaches were taken and such systems are now manufactured by at least four companies.

The capabilities developed in these integral systems are permitting development of highly refined in-flight weight and center of gravity control systems.

These efforts were further developed for civil aircraft, primarily the large wide-body jets.

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(5) R&D Costs

The R&D cost is estimated at $500,000. In addition, each aircraft program allotted funds to the particular load adjuster for their aircraft.

It is estimated that the Air Force has expended on the order of $5,000,000 for weight and center of gravity measuring equipment for airplanes and helicopters since the mid-fifties. Sales of this type equipment are probably approaching the $30,000,000 level.

B-3. Fatigue Testing

(1) Early Development

Fatigue has always been a problem in structural design. It was the cause of the first airplane crash to result in a fatality, Lt. Selfridge, a passenger in a Wright brothers airplane at Fort Myer, Virginia in 1908. At that time and for several years thereafter, fatigue was referred to as "Crystallization". And, except for flying and landing wires and their fittings, the major fatigue problems prior to World War II were encountered in engines and propellers.

Prior to and during World War II, static strength design conservatisms and moderate performance demands provided an inherent fatigue resistance in the primary aircraft structure - in spite of the fact that there were no requirements for specific fatigue life in aircraft. With the advent of jet aircraft, initially the jet fighter aircraft, the increased performance demands along with the ease of pilot induced high maneuver load factors eliminated this built-in fatigue resistance and fatigue failures started to develop. Because of these failures and due to the development of improved test methods and equipment that made possible rapid full-scale wing fatigue tests, these problems were attacked by means of laboratory tests, the results of which were then correlated with service experience to establish a final fix.

(2) Flow of Technology

The first full-scale component fatigue tests to be initiated utilizing electro-hydraulic load control were on the wings of the AT-6 and the nose gear of the A-26 aircraft in the mid forties at Wright Field. The first use of full-scale fatigue testing to correct service life deficiencies was on the F-84D in 1948. The first military requirement for spectrum loading on landing gear was established

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in 1953; the initial requirement for a multiple-component multiple load level fatigue test program to solve the existing B-47 problem was established in 1958 with three concurrent test programs conducted at Boeing-Wichita, Douglas-Tulsa, and NASA-Langley; and a plan for avoiding service fatigue problems, the Aircraft Structural Integrity Program (Ref. 13) was approved by Headquarters USAF on 16 February 1959.

(3) Civil Aviation Benefits

The first commercial full-scale airframe test to predict service life was accomplished in 1947 on the Martin 202 aircraft. Improved test methods and instrumentation made rapid full-scale tests possible, and continued development has taken place to improve these techniques. The Air Force's Aircraft Structural Integrity Program benefited many civil transport aircraft such as the Beech Model 18, the Boeing 707 series and the Lockheed Hercules. Benefits also accrued to the Convair Atlas and the Douglas Thor launch vehicles which are work-horse boosters for the civilian satellite (COMSAT) projects. The advanced full-scale fatigue test techniques pioneered by the Air Force are currently in use as industry standards.

(4) Subsequent Development

Continued development has taken place to improve full-scale fatigue test techniques - primarily in the development of highly flexible, load programmable, electro-hydraulic closed loop, servo controlled, loading systems (Refs. 14 and 15). These advancements have provided the test capability to simulate more accurately the flight loads on the test article, including the capability to conduct the full-scale fatigue tests on a flight-by-flight loads basis. The stimulus for this development, both within the military services and industry, was primarily the Air Force Aircraft Structural Integrity Program launched on all first line Air Force aircraft in 1958 and continuing to present. Recent efforts within the Air Force (Ref. 16) and NASA (Ref. 17) have been addressing the problem of "real time compression" in conducting full-scale fatigue tests on high performance aircraft which experience long cruise times at sufficiently high Mach numbers to introduce elevated temperature effects on the structural fatigue performance.

(5) R&D Costs

The Air Force expended approximately $1,000,000 R&D funds during this time period in developing advanced test techniques. Also, considerable development in fatigue test technology was a by-product of the many full-scale fatigue tests conducted in-house by the Air Force.

The Navy also conducted a comparable R&D program in this time period and also conducted many in-house full-scale fatigue tests.

B-4. Fibrous Composite Structure

(1) Early Development

In the early 1940's, at about the same time that glass fabric polyester laminates were being utilized in the design of radomes, a pioneering effort was started in the design and development of aircraft primary structural components utilizing these laminates. These concepts not only utilized glass fiber laminates, but made extensive use of sandwich construction.

The Aircraft Laboratory at Wright Field, Ohio, selected two current trainer aircraft as base point vehicles to develop and prove these structural concepts. The BT-15 airplane, a single engine, low wing, fixed gear, all metal trainer was selected for the first project. The monocoque aft fuselage section was redesigned as a plastic laminate sandwich construction utilizing glass cloth fiber faces with an end-grain balsa core. The fabrication of the fuselage section was completed on 7 November 1943 and static tests successfully completed for all basic BT-15 design conditions between 11-15 November 1943. A second test article was constructed and successfully flight tested on a BT-15 on 24 March 1944 (Ref. 18).

The second, and more ambitious project, was the redesign of the entire outer wing panel of the AT-6C advanced trainer aircraft utilizing glass cloth laminates -- both as solid laminate and in sandwich construction. The only metal parts utilized were the wing attach bolt angle at the root, and the normal metal flap and aileron hinge brackets. The sandwich concept utilized in this project employed cellular cellulose acetate as the core material with glass fabric polyester face sheets. Fabrication of the first wing panel was completed on 31 May 1946 and static tests were completed on 10 September 1946. Several additional wing panels were fabricated, installed on service AT-6C aircraft, and flight tested for an accumulated 1,600 hours of flight time (Ref. 19).

At a somewhat later date, in the early 1950's, the Army supported the development of a plastic tail cone for the Cessna L-19 airplane.

These early applications of reinforced plastic sandwich construction were reasonably successful, considering their pioneering

nature. Why then weren't they quickly followed up by application to subsequent military aircraft? One answer is that the load conditions for the higher performance aircraft were more severe than for the small trainer aircraft. Also, the modulus of elasticity of these new glass reinforced plastics was too low to completely satisfy design requirements for primary structures on the newer military aircraft. In addition, the work on the AT-6C plastic wing defined some problems of reinforced composite structures that still plague us today. For example, some quotations from the report covering the work are as follows:

"The efficiency of the attachment of the metal fitting to the glass laminate of the .... wing panel is low. Further work is necessary on the design of bonded and bolted joints to improve the efficiency.

The low elongation of glass fiber laminates has an appreciable effect on the stress distribution in the structure and should be given serious consideration in the design of glass plastic structures.

The low resistance of glass (fabric) laminates to cleavage should be considered in the design of such structures."

(2) Flow of Technology

This technology has progressed through the years to a point where fibrous composites (glass, boron and carbon fiber) are used both in primary and secondary structures in present day aircraft both civil and military. Twenty-five rudders for the F-4 have been fabricated and are now on service aircraft (Ref. 20). Also, a horizontal tail section incorporating boron/epoxy has been fabricated and tested for the F-111, and is currently flying in the Tactical Air Command (Ref. 21).

(3) Civil Aviation Benefits

This technology has been transferred to the civil sector. Glass fiber composite structures have been used in a number of small aircraft such as Taylorcraft model 20 certified in 1955 and Piper PA-29 and many others. The Douglas DC-8 jet airliner has over two thousand pounds of fiber glass composites. The most unique utilization of fiber glass in this airplane is the isolation section at mid height of the vertical tail that allows the upper portion of the vertical tail to act as an antenna*. The Boeing 747 aircraft utilizes 5000 pounds of fiber glass parts in secondary structures. These parts

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*This concept was first developed by the Air Force in the 1950-1951 time period and demonstrated on a C-54A airplane using the outer wing panel.

are approximately 33% lighter than similar metal parts. Fiber glass is used on many aircraft in the fabrication of electrically heated de-icers for wing leading edges.

(4) Subsequent Development

Subsequent R&D has been and still is being accomplished to improve on the early development of fiber composites. In fact, new fiber material has been introduced such as boron and carbon, which will increase the strength and structural efficiency of the composite. With the added strength of the advanced filaments, the weight of aircraft structural parts can be reduced 30 to 40 percent over comparable metal design.

The Navy F-14 aircraft employs these advanced composites on the horizontal tail, and the Air Force B-1 utilizes advanced composites as reinforcement on structural elements (for example, the main fuselage longeron) where increased rigidity is needed.

(5) R&D Costs

Over the past five years it is estimated that approximately 50 to 60 million dollars has been spent in R&D on composite structures. This figure includes military, company IR&D as well as corporate funds.

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SECTION II-C
FLIGHT CONTROL

In this subsection of Significant Advances Since 1925, three significant advances are described: (1) Instrument Flying; (2) Autopilot and Flight Control; and (3) Load Alleviation and Mode Suppression. Instrument flying can be traced from the early flying days of Lt. James Doolittle of the Army Air Corps, who pioneered blind flying in the late 1920's and 1930's. This pioneering work has resulted in continuous development of flight instruments and instrument displays and has permitted instrument flying to be accomplished in a routine fashion by thousands of average pilots. This work has further led to optimal pilot control and to displays compatible with the roles of operational use of the aircraft. Automatic flight control system technology has evolved from the point where it initially served as a pilot work load relief function to the point where total dependence on the augmentation function is essential for vehicle flight such as in the Apollo mission. Operational utilization of both commercial and military aircraft will be significantly enhanced by the expanded functions of automatic control such as all weather landing, enroute navigation and mission management. Automatic control techniques will have significant impact on aircraft designs such as supersonic transports to reduce trim drag by reduction of subsonic static stability margin. STOL and VTOL transports will require the broad application of augmentation and automatic control techniques to permit them to repeatedly operate safely at low speed flight. Load alleviation and mode suppression technology actively controls the structural response of flexible aircraft. It is a modern breakthrough in large aircraft technology. This capability offers the potential of lighter structures, improved ride qualities and extended structural fatigue life.

C-1. Blind Flying and Instrument Flying

(1) Early Development

In 1922, J.H. Doolittle performed the first crossing of the United States that was accomplished in less than 24 hours. Hampered by considerable bad weather and darkness, Doolittle claimed that the trip would have been impossible without the "blessed bank and turn indicator." The instrument was invented by Elmer Sperry in 1917 and was obtained by Doolittle (then an Army Lieutenant) through Army Air Service Engineering at McCook Field in Dayton, Ohio. This adventure described by Doolittle in his 1961 Gardner Lecture, undoubtedly marked the beginning of instrument flying. Doolittle acclaimed the "blind flying" pioneering exploits of Ocher, Myers, Crane, Wolf, Kelsey,

and a number of other military aviators that provided the fortitude, persistence and brains behind the blind flying experiments of the twenties and early thirties. On 24 September 1929, as a sequel to a costly, yet unsuccessful experiment in fog dispersal, Doolittle performed the first flight that from take-off through landing was performed entirely on instruments. The landing was performed with the aid of a radio range localizer, marker beacons, and a Kollsman altimeter. Many milestones in instrument flying were reached in the 1930's. In 1934 for example, Captain Albert Hegenberger, U.S. Army Air Corps, was awarded the Collier Trophy for the development and demonstration of a successful blind landing system. The work of Hegenberger marked the transition between eras in the history of flying. Earlier, progress was noted by daring feats of pioneering aviators. Although none the less important, luck was often a major contribution to the success of these feats. The work of Hegenberger marked the beginning of the time when the pacing factor in technological and operational advance is engineering expertise.

Volume instrument flying started in the late thirties. In 1937, over 3000 hooded instrument approaches were performed by commercial DC-3 pilots as well as Army and Navy pilots. Also in 1937, Captain Crane and Captain Holloman, engineers and pilots at Wright Field, Ohio, performed the initial experimentation on autopilot control, and automatic blind landing.

During World War II and in the late 1940's and early 1950's emphasis was placed on the development of ground based aids to instrument flight, i.e., radio guidance and navigation systems. The SCS-51 instrument landing system was used extensively by the military in World War II. It used a five-loop Alford antenna array for localizer and an earth reflective glide slope. This system was the forerunner and provided the technology for the commercial Instrument Landing System (ILS) as it is known today.

The development of control instrumentation including both flight and engine instruments, sensors, transducers and computers has been a broad, multi-discipline area of work. Through World War I, aircraft instrumentation was the simplest type and generally consisted of adaptations of instruments already existing. Since that time, aircraft instruments have had a distinctive character which resulted from a purposeful effort pointed toward a particular application. This development has been supported almost entirely by the military. These developments have been adopted, generally with no significant changes, by commercial air carriers.

With regard to gyro instruments, the first work on this subject goes back to 1918 when Sperry first experimented with them. By 1930, rate gyros and simple air-driven displacement gyros and artificial horizons had been developed. When the Army Air Corps experienced difficulty in flying the Air Mail in 1934, these instruments were quickly employed to extend their blind flying capability. Commercial flyers then also began using these instruments. During and shortly after World War II, the electrically powered gyro instruments were developed. This permitted better accuracy and reliability in these instruments. A few years later, the commercial airlines began using these electrical instruments.

During the latter part of World War II, it was discovered that a knowledge of the Mach number at which the airplane was traveling was an important parameter in keeping the airplane under control. The Air Force jointly developed this instrument for use on all aircraft capable of approaching or exceeding Mach 1. This instrument was generally adopted by commercial airlines a few years later.

It was beginning to be apparent in 1945, that more sophisticated air data information would be helpful in the precise control of aircraft. Serious development work was begun about 1950. In 1952, the first central air data computer was installed on the B-52 aircraft. All air data functions were not provided, however, on the first application. The first aircraft to have a complete system was the F-101 about 1954. The B-58 was the first bomber and the C-141 was the first transport. Later, the Boeing 707 was the first U.S. commercial aircraft to employ a limited central air data computer. The 727 and 737 and later aircraft have complete central air data computer units.

(2) Flow of Technology

As mentioned earlier, the significant advancement in instrument flying technology have been made almost exclusively by the military or through military sponsored programs and this technology has almost without exception, transitioned to civil use. The transition is accomplished through flying demonstrations, technical data dissemination, the adoption of common civil-military specifications and standards, civil participation in military programs and through the initiative and competence of American industry. The number of control elements, particularly instruments, that have been involved in the technology transition related to instrument flying is probably in the hundreds. It is only possible to cite a few examples.

Operational implementation of force wheel steering took place on the C-141 aircraft in 1965. This technology transition resulted from a series of coupling meetings involving the development engineering people, the system managers, the users (Military Airlift Command) and the FAA.

During 1965 and 1966, the USAF undertook further validation work on the Integrated Manual-Automatic Landing System to provide the functional solutions to the airborne portion of the instrument flying and all weather landing problem. The participating pilots took the position that force wheel steering is absolutely essential to low weather operation. A film was made fully describing the low weather investigation and numerous presentations were made throughout the country in 1966, 1967, and 1968, showing the film and demonstrating the system. The national aviation community was made aware of the breakthrough which had been accomplished.

During this same period, the Army and Massachusetts Institute of Technology developed helicopter instrument flying technology to simplify the pilot's task of navigating and controlling these craft in the tactical environment. In this Tactical Air Guidance System (TAGS), the pilot expressed his intent as a velocity vector input which fly-by-wire and inertial components executed automatically. Built-in test equipment in TAGS assured the system's functionability. Subsequent developments have continued this practice.

(3) Civil Aviation Benefits

Certainly, civil aviation has benefited by the technology generated by the military in instrument flying. The integrated manual-automatic system which resulted from the USAF Pilot Control-Display Factors Program provided a timely alternate to the pure hands-off system. Operationally, basic elements of the system are being employed to make better use of the autopilots presently on board the aircraft. The elements of the ultimate low visibility landing system are on board those aircraft, providing the necessary foundation for introducing the remaining components in an evolutionary fashion.

In a letter to the USAF dated 7 May 1964, Mr. W.M. Magruder, Chief Development Engineer, Lockheed-California, stated, "I appreciate being included in this effort (as a subject pilot) and can assure you that the experience gained here will do the Lockheed Company a great deal of good - not only in our supersonic transport efforts but in any blind landing efforts that we undertake in the near future including the C-141 and even possibly the Electra." Mr. S.G. Granger,

Director of Research and Development for Trans World Airlines, in a letter to the Air Force dated 2 March 1963 stated, "The test being undertaken in the Pilot Factors Program certainly should produce some rather firm conclusions due to the broad spectrum of pilot experience being analyzed in this study. Too frequently, pilot input is left until the actual testing of the production vehicle whereas in this type of approach conclusions can be reached prior to concluding the design of an airplane that will satisfy all facets of the industry whether it be the military, the airlines, or the manufacturers."

(4) Subsequent Development

There is a continuing program within the government and industry to update and improve instrument flying capabilities and conditions. In recent years the other Services, NASA, and the FAA have become involved in programs to develop multi-function display devices, head up displays, guidance and navigation elements, direct lift control and other concepts that are related to instrument flying.

Pressing requirements to improve the operational, all weather capability of its new aircraft without compromise to flight safety were established by the world aviation community in 1960 at an International Air Transport Association meeting in Rome. The focal point of concern was the impending introduction of supersonic transports. The performance of the aircraft, coupled with procurement and operating costs, demanded that the aircraft be relatively free of economic penalties imposed by bad weather. Reliable operation in the terminal area was particularly crucial to making the aircraft profitable as well as safe.

At the time, the only option open for obtaining a low visibility landing capability was the pure, hands-off solution proposed by the British. There was no alternative on the world market to the expense and complication of duplex and triplex systems. The American aviation community took strong exception to the pure automatic approach because it: (1) infringed upon the command role of the pilot; (2) compromised the pilot's capability to act as a back-up in the event of partial system failure; and (3) would result in high procurement and maintenance costs.

In response to this need, the USAF proposed to the National Supersonic Transport Development Panel, chaired by Mr. K.E. Power, FAA, in 1961, that the USAF Pilot Control-Display Factors Program (Pi-Fax) be established to develop and demonstrate an alternative to the pure automatic approach that would meet the requirements set forth by the U.S. aviation community.

Air Force experts in instrument flight provided the technical expertise, and engineering developments were accomplished on USAF flight test aircraft. Those concepts which appeared promising were mechanized and flown at the Instrument Pilot Instruction School in a series of carefully controlled flight tests to obtain pilot acceptance and objective performance data.

Elements of the system were an autopilot, force wheel steering, the flight director system, flight path angle system, a radar altimeter, and associated displays.

The autopilot and force wheel components were installed and flown early in 1963. The results were reported in Working Paper 115 at the 15th IATA Technical Conference held in Lucerne in April 1963. The concept of marrying the pilot and autopilot modes of flying by means of integrating the flight director and autopilot into a single computer and introducing force wheel steering was acclaimed by all subject pilots without exception. In less than 18 months, the USAF provided an alternative to the all-automatic approach to the world aviation community.

Between July 1963 and December 1964, a second phase was conducted by the USAF once again using pilots drawn from throughout the United States in addition to five pilots (Swiss Air and BOAC) from overseas. The effectiveness of flight path angle and absolute altitude in making approaches was validated. These results were reported in a paper given to the International Flight Safety Forum in 1965 at Madrid.

In less than three years, over 10,000 instrument approaches had been accomplished. The Air Force provided the technical skills, the technology, and the facilities - - particularly the aircraft - - to accomplish the program.

Commercial aviation has picked up the technology developed in the USAF Pilot Factors Program. The Boeing 737 was the first commercial aircraft to have force wheel steering modes available. The concept of the integrated flight director-autopilot has been employed in the Boeing 747 The Lockheed 1011 and McDonnell Douglas DC-10 have both integrated computer and force wheel steering modes. In general terms, there was a lag of approximately three years between introduction of the force wheel concept and the implementation in the 737. It took five years for the integrated flight director-autopilot computer to be applied. Flight path angle display was intended

for the supersonic transport; however, cancellation of the project terminated the only effort directed to bringing path angle into the cockpit on an operational aircraft.

(5) R&D Costs

The R&D investment in instrument flying has probably been well into the hundreds of millions. The number of contracts and programs that have made a technology contribution is in the thousands. However, because the technology in this area has evolved over such a long period of time, the exact costs are difficult to obtain. Recent estimated costs are: Pilot Factors Program, 6 million, Air Force; Carrier Landing Program, 50 million, Navy; Tactical Landing System, 3 million, Army.

C-2. Autopilot and Automatic Flight Control

(1) Early Development

Early autopilot developments had little theoretical background and were based primarily on the ingenuity of such men as Lawrence Sperry who flew the first automatically controlled aircraft in 1914*. His designs evolved through the years to the point where the A-2 three-axis autopilot was employed in several commercial aircraft in the late 1930's. In 1933, Wiley Post successfully used this autopilot in his round-the-world flight in the Lockheed Vega 5-C. The system included gyros with pneumatic pick-offs and three-axis control with proportional hydraulic servos.

British contributions began in 1926 with analysis of lateral-directional dynamics and development of a two-axis automatic control system which exhibited improved maneuvering control over the Sperry design.

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*McRuer, Askenas, Grahm, Aircraft Dynamics and Automatic Control., TR No. 129-1, Naval Air Systems Command, Department of Navy, Washington, D.C., August 1968

In 1935, the German Siemens autopilot provided elevator control from an airspeed sensor and rudder control as a function of a magnetic compass. Hydraulic servos and rate gyro feedback completed the design. During World War II, Siemens concentrated on single-axis course controllers, and over 80 percent of the German aircraft were equipped with similar automatic stabilizers. Later in the war, Siemens introduced the K-23 all-electric fighter controls which moved the control surface at a rate proportional to body axis rotation.

During World War II, four electric autopilot designs were principally employed which could accept maneuver commands either from the pilot or from guidance sensors: (1) the C-1 autopilot, built by Minneapolis-Honeywell, installed in four-engine bombers such as the B-17, B-24, and B-29. It used electrical positioning servos to drive the control surface and could be slaved to the bomb-sight; (2) a General Electric design suitable for installation in fighter aircraft; (3) a Sperry A-5 autopilot that included altitude control; and (4) in 1954, a Bendix A-10 autopilot that included a flux-gate compass for automatic heading control and a yaw rate feedback.

During the war, two important features evolved which were essential for the continued growth of automatic control systems: (1) feedback control theory, and (2) electronic computers for analysis and simulation.

After the war, the Sperry A-12 and Bendix PB-10 autopilots introduced landing approach couplers, and the Bendix system had automatic throttles. Lear developed magnetic power clutches in their F-5 autopilot to avoid power amplification problems for positioning the control surfaces. Other autopilots developed during this time period included the F-1, E-4, E-6, and E-11 systems. Some of these autopilots were later installed in B-36, B-47, B-66, and B-52 bombers; C-124, C-130, C-121 and C-133 transports, and the F-86D, F-84, F-100, and F-101 fighters.

(2) Flow of Technology

There are few examples of new flight control technology in which a clear cut path from initial development to application in advanced military weapon systems or commercial aircraft are clearly visible. The normal situation is one in which new ideas in control principles and components are developed by several agencies. The

designers for a new aircraft automatic flight control system can then select the best features from each of these developments and apply them to his particular airplane. Automatic flight control systems must be tailored to each particular aircraft design due to the fact that their stability and control characteristics are unique. Little commonality in design other than sensors can be applied to more than one application.

Probably the simplest form of technology transfer is to involve prime contractors in the development cycle of flight control systems. This exposure educates a large design team with the advantages and practical problems involved. It is also essential for prime airplane contractors to be convinced of the validity of new technology. Avionic flight control contractors can apply the latest electronic components and packaging techniques but the overall flight control design is most often laid down by the prime contractors.

An effective means for dissemination of flight control development information and results has been through professional papers, symposiums and aviation committees. Some of these committees formulate standards and specifications which are then circulated throughout government and industry for coordination.

New techniques are sometimes demanded because the existing system approach is unsatisfactory for a more advanced application. Supersonic transports may require considerably advanced flight control technologies such as "hard" SAS, digital AFCS with expanded built-in-test and monitoring functions, and quad force-summed servo-actuators. These are not yet applied in any flight control system in commercial or military transport.

For flight control technology, R&D cycles often require five to ten years for major advancements. Flight testing is considered essential for final demonstration, and this may result in two or more different aircraft installations to achieve satisfactory refinement. In the past, military applications of advanced flight control technology often led commercial applications by several years. Recently, this trend appears to have been reversed. In the case of the Boeing 747, the McDonnell Douglas DC-10, and Lockheed L-1011, the automatic flight control systems have more advanced capability than do any of the military transports.

(3) Civil Aviation Benefits

Considerable automatic flight control technology developed by the military has found application in commercial transports. Principal applications have included: (1) refinement and test of control laws such as control wheel steering for various modes of operation; (2) highly reliable, redundant electronics and monitoring schemes; (3) built-in-test features; (4) auto-throttle functions; and (5) fully powered controls. All-weather landing features considerably increase the economic situation of commercial transports. Stability augmentation sensors, control laws, and design techniques were readily available for application. Direct lift control schemes pioneered by the Navy and the Air Force are in use on the L-1011. Supersonic transport designs that satisfy range requirements are feasible if smaller horizontal and vertical tail surfaces are used and the resulting reduced static stability margins are compensated by control system augmentation. STOL transports will require full-time augmentation controls for low-speed flight, particularly in the event of failure of an engine. STOL approach techniques are analogous to techniques developed for Navy carrier landings. "Iron-bird" test facilities originally established by the military for checking complete flight control systems prior to flight have become a way of life for commercial transports also.

(4) Subsequent Development

During the 1950's, the most advanced automatic flight control system was the F-106 Hughes digital system. Complete mission capability could be flown automatically from takeoff through landing including navigation, data link vectoring from the ground, and attack intercepts. Practically all high performance fighter aircraft required stability augmentation to achieve satisfactory handling qualities. Air data scheduled gain changes and self-adaptive control theory evolved during this time period. Fully powered hydraulic actuators came into common use in military aircraft during the 1950's.

Greater emphasis was placed on the combined controllability and maneuvering performance of automatic flight control systems in the 1960's. Self-adaptive control schemes were developed and applied successfully in the X-15 and later in the F-111. Augmentation became an essential part of the primary flight control system for aircraft such as the F-111, F-4, and A-7 and were nearly as important to DC-8's and 707's. To achieve adequate stability and control, high authority control augmentation systems were developed which applied various levels of redundancy so that normal mission operation could be continued with one or more failures. Redundancy was made feasible through the great advancement in microelectronics and integrated circuits. Built-in

test equipment (BITE) was also added to achieve a rapid system test just prior to take-off. Initial fly-by-wire (no mechanical controls) developments and flight test feasibility tests were undertaken.

Continuous development is underway for automatic flight control systems and augmentation techniques. Each new application represents some advancement in technology although it is most often a slow evolutionary advancement rather than a major step forward such as fly-by-wire. Emphasis in development programs is now on safety, performance, reliability, maintainability, survivability, etc. Inter-disciplinary technical advancements of flight control with structural, flutter, propulsion, and weapon delivery designs are now being attacked. Air Force developments and flight test evaluations are underway in fly-by-wire, digital FCS, multi-mode controls, multi-plexing techniques, helicopter and V/STOL augmentation schemes and take-off and landing controls for large cargo transports. Navy developments include digital flight controls, auto-throttle, anti-submarine AFCS modes for aircraft and helicopters, and direct lift controls. Army developments strongly emphasize helicopter controls. An Army program initiated in 1961 with MIT to investigate direct control of linear velocity (instead of angular velocity) provided significantly improved capability for operating under adverse weather conditions. An Army effort with Canada has been underway since 1968, Tactical Aircraft Guidance System (TAGS), which integrates linear velocity control including navigation functions from flight control components and fly-by-wire mechanization into a total guidance concept for VTOL aircraft. NASA will be flight testing a digital flight control system, STOL landing and automatic terminal area navigation, and major efforts in space shuttle automatic and manual controls.

(5) R&D Costs

Military R&D investment in automatic flight control system technology was of the order of 12 million dollars through the end of the World War II. From the time period of 1945 through 1960, approximately 50 million dollars was expended on development of autopilots for new military aircraft and advancement of this technology. From 1960 to the current time, approximately 50 million more dollars were invested. For example, a major advancement in flight control such as the Survivable Flight Control System ADP providing full man-rating of fly-by-wire cost 16.7 million dollars including flight testing.

C-3. Load Alleviation and Mode Suppression

(1) Early Development

The subject of alleviating aircraft response to gust encounter has been of interest to aircraft designers for many years with early

experiments on modern aircraft being conducted in the early 1950's. These early tests showed that gust loads could be reduced by use of the aircraft autopilot. However, there existed no driving requirement to perfect the techniques at that time, and the technology lay rather dormant.

However, the requirement to increase aircraft operational capabilities in terms of speed, range, and payload resulted in a trend toward aircraft configurations which are more sensitive to excitation of structural responses. The quest for high speed led to thin wings for aerodynamic efficiency which in turn required the use of high strength materials in wings to assure adequate strength. The result was lower structural resonant frequencies. In addition, the requirement for larger payload and range capabilities resulted in larger overall structures which also tended to drive the natural frequencies downward. The trends noted have led to contemporary configurations which have natural frequencies of the lower modes of oscillation in the 0.75 - 1.0 Hz and flutter modes in the 2.0 - 5.0 Hz range. Natural structural resonances in this region are highly susceptible to excitation by pilot command (in the order of 1 Hz) and the high energy portion of the gust spectrum.

The situation is further complicated by the fact that these more sophisticated configurations have also resulted in increased dependence on the automatic flight control system to provide acceptable flying qualitites. This then, led to interaction problems between the flight control system and the structural resonances.

One of the earlier encounters with this interaction problem came on the B-36 aircraft where the control system was found to excite one of the lower structural modes, then sense the excitation and operate to reinforce the excitation. The problem was resolved by sensor relocation and filtering the control system signals so as to make it insensitive to the structural resonant frequency.

The techniuqe of restricting control system performance to avoid the interactions was successful for some time but finally became unacceptable as the structural modes approach the pilot command frequency spectrum. Attempts to use avoidance techniques on these problems resulted in unacceptable operation of the control system in its primary function, i.e., to improve flying qualities. The criticality of the situation led to the initiation of research to establish the feasibility of actively controlling aircraft structural responses.

The first major program to address this began in August 1965, under the title, Gust Alleviation and Structural Dynamic Stability Augmentation System (GASDSAS). The primary emphasis was to analytically show ride improvement and gust load alleviation for the low altitude, high speed penetration mission and used the XB-70 as the basis for the

analysis. The program was completed in October 1967 (Ref. 1).

During the same time period, the impact of pilot and high energy gust excitation of structural resonance in reducing fatigue life also became apparent. Initially it was recognized that the B-52 fleet was using up the predicted fatigue life more quickly than expected. Structural modifications were performed but the problem was not solved since unmodified portions of the aircraft then became fatigue critical.

The serious nature of the fatigue life problem led to initiation of research which provided the basis for an advanced development program called Load Alleviation and Mode Stabilization (LAMS) in June of 1966. The performance criteria was fatigue damage rate reduction. This was a flight test program which demonstrated a 50% reduction in the fatigue damage rate due to turbulence encounter for the B-52 test aircraft using existing control surfaces to resist induced structural response. In addition to improving fatigue life, the LAMS control system also provided experience with the vastly improved controllability of the vehicle. Experiments investigating the usefulness of direct lift control (DLC, the variation of lift with wing control surfaces rather than pitching the aircraft) for precision maneuvers were conducted. These showed the tasks of aerial refueling and instrument approach to be greatly simplified by the availability of DLC. Other experiments also showed the immunity of the LAMS test aircraft to upset by wake vortex encounter. The technical activity under the LAMS Program was completed in August 1970 (Ref. 2).

(2) Flow of Technology

Traditionally, acceptance of new automatic flight control technology is dependent upon successful completion of a flight test program. This flight validation allows those contractors involved to gain experience in application of the devices and techniques. Such experience provides the confidence to propose advanced concepts for use in new vehicles. On the other hand, the existence of validated flight test data provides a basis for the systems project offices to judge the validity of the proposals.

Although this is the usual procedure, variations have also been successful. In the case of the B-52 fleet fatigue problem, the urgency required a slightly different approach. In this case, an engineering change proposal (ECP 1195) was initiated to investigate the problem. Based on the preliminary research in the early 1960's which led to the GASDSAS (Gust and Structural Dynamic Stability Augmentation System) Program it was known that a good rigid body (flying qualities)

flight control system would improve the fatigue rate of an aircraft, particularly in the lateral degrees of motion. Since the basic B-52 configuration included an extremely low authority yaw damper, and no powered control surfaces, this was the area that was investigated. ECP 1195 was initiated in September 1965 to develop a high quality yaw damper. The final configuration resulted in relatively high authority automatic rate dampers in both pitch and yaw and gave significant fatigue improvements in the aft fuselage and tail. The ECP 1195 system did not address any possible fatigue improvement in the wing because a previous structural modification had eliminated concern in this area. The retrofit of the B-52 G&H fleet to include the ECP 1195 system was completed in August 1971.

The successful tests of the LAMS system in 1967 and 1968 and a test on the XB-70 of the GASDSAS concept in October and November of 1968 provided the confidence necessary to include a form of structural mode control in the B-1 design, and improve crew ride environment through active control.

The primary mechanism for technology transfer is the involvement of the various contractors in the development of the technology. An example of this is the willingness of Boeing and North American to propose use of this technology on the B-1. In the case of Boeing, the LAMS Program and ECP 1195 provided the necessary experience and in the case of North American, the GASDSAS Program and the XB-70 tests provided the experience.

The time lags in technology transition is largely a matter of operational requirement. In the case of the B-52, the ECP 1195 provided a solution to a serious problem. On the other hand, the LAMS and GASDSAS efforts have provided a firm technology base which is being incorporated into new aircraft developments as in the B-1.

(3) Civil Aviation Benefits

The benefits of this technology have not yet been widely applied to civil aviation. However, spin-offs are beginning to appear. The Lockheed 1011 commercial transport already has incorporated a direct lift control system that is directly traceable to the LAMS B-52 demonstration. Previous DLC devices had been developed by Douglas for the A3D and by Vought for the F-8 airplanes under Navy programs. On the L-1011 DLC is used to improve instrument landings and reduce touchdown dispersion.

(4) Subsequent Development

Subsequent to the major programs noted above, continuing efforts have been made by both military and civilian research organizations to extrapolate the technology base to additional functional capability. Specifically, military sponsored research has shown the feasibility of controlling unstable structural modes (flutter) through active systems. Also, the impact of direct force control (both lift and side force) on improved weapon delivery has been validated.

In the civilian sector, NASA has evaluated the application of ride control for STOL type transports with favorable results and has also initiated joint programs with USAF in the development of active flutter control devices.

(5) R&D Costs

The approximate costs of the major programs noted above are as follows:

GASDSAS (analytical)	$	400K
LAMS		6,000K
XB-70 Tests		400K
ECP 1195		11,000K

The differences in the relative magnitude of the various test efforts is based on the desired end objective. In the case of the XB-70 tests, the intention was to obtain experimental verification of the GASDSAS principles with no attempt to obtain maximum performance. This approach resulted in minimum vehicle modification. In the LAMS Program, the intent was to develop an integrated control system and obtain maximum benefits. The ECP 1195 effort was to develop a complete prototype system to solve a specific problem and which was intended for fleet retrofit. These ECP 1195 costs only include the developmental costs and do not include fleet retrofit costs. All of these research funds were provided by the USAF. In order to achieve an equivalent technology base, the civilian research community would have had to expend, as a minimum, the costs of the GASDSAS, XB-70 tests, and the LAMS Program, approximately $7.0M.

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SECTION II-D
VEHICLE DYNAMICS

In this section of Air Vehicle Technology, four closely related significant advances are described: Vibration Reduction, Flutter Prevention, Acoustics, and Sonic Fatigue. Because of the close relation of aircraft flutter and vibration to the safety of flight, this work is of great concern to the Military Services and to both the research and regulatory agencies of the government. Flutter and vibration became established technologies about 1938, largely because of developments in non-stationary aerodynamic theory and in adequate flight test instrumentation. Aircraft acoustics became important with the development of the enclosed airplane, particularly the bomber and transport airplanes initially from a passenger comfort standpoint but later from the standpoint of pilot to crew inter-communication on long range bombing missions of World War II aircraft. NACA did pioneering work in the 1930's in airplane acoustics; the Air Corps accelerated their efforts in 1940. Sonic fatigue was a later technology that had a large effect on structural design due to the thrust levels of turbojet engines developed for bomber and cargo aircraft about 1955.

D-1. Vibration Reduction

(1) Early Development

The increase in horsepower of internal combustion engines between 1930 and 1940 (from a level of about 525 hp to 1200 hp) introduced problems of vibration in airplanes. In particular, the torsional vibration problem in radial engine crankshafts led, in 1934, to a joint program by the Bureau of Aeronautics, U.S. Navy and the Massachusetts Institute of Technology for the purpose of developing an electrical recording instrument suitable for the quantitative measurement of torsional crankshaft vibration. In 1935, this work was extended to include the development of suitable instruments for the measurement of linear vibrations of engines and airplane structures as a whole. This work, accomplished under Bureau of Aeronautics Contract 46476, made possible the recording of vibrations of airplanes during flight. The instrumentation, developed in MIT's Aeronautical Instrumentation Laboratory under Dr. C.S. Draper, included linear vibration pick-ups, integrating amplifiers, and a recording oscillograph. With the capability offered by the commercial development of this instrumentation (Sperry Gyroscope Company and Consolidated Engineering Corporation), the vibration and flutter technology rapidly advanced. Some of the first flight vibration surveys were made in 1936 by the Massachusetts Institute

of Technology on the Grumman FF-2 and Grumman F-3F Naval airplanes and by Lieutenant Fred R. Dent, Jr., of Wright Field on an Air Corps Stearman PT-13 airplane.

During the same period in which instruments were being developed to measure and record airplane vibration, work was also underway to reduce the engine generated vibrations that were transmitted into the airplanes. With the trend toward increased reciprocating engine horsepower, the vibratory forces were growing in magnitude. In addition, the metal airplane resulted in stiffer structures so that the natural frequencies of the structure fell into the same frequency range as the engine and propeller vibratory forces, thus resonating the structure and drastically increasing vibratory stresses and amplitudes. Studies by the Air Corps of the important forces generated by engines and propellers, combined with the theory of flexible mountings, led to the development of a "six-degree-of-freedom" vibration isolating engine mounting system. Although engine mounts to isolate vibration about the torque axis had been developed for automobiles about 1928, the alternating forces and moments generated by the engine propeller combination required that the engine be isolated in its three translational and three rotational degrees of freedom; hence the term "six-degree-of-freedom" mounting (Ref. 1). This engine mounting system was first installed in an Air Corps modified Curtiss YA-8 airplane and in the Stearman PT-13 airplane referred to above.

Professor E.S. Taylor of the Massachusetts Institute of Technology developed the principle of "dynamic suspension" and working with K.A. Browne of the Wright Aeronautical Corporation, developed an engine mounting system which achieved effective isolation, elastic decoupling of the modes of vibration, and virtual center of gravity suspension of the engine (Refs. 2 and 3). K.A. Browne was awarded the Wright Brothers Medal (SAE) in 1939 for his work on "Dynamic Suspension - A Method of Aircraft Engine Mounting". His definitive paper was presented at the Annual Meeting of the S.A.E. at Detroit, Michigan, on 10 January 1939.

The early dynamic suspension systems were found to provide effective vibration isolation in five degrees of freedom (the exception being high stiffness in the fore and aft direction). This introduced later problems involving propeller blade vibration which, however, were resolved by Wright Field engineers (Ref. 4). Dynamic suspension systems were made available to all airplane contractors for military airplanes with the enthusiastic approval of the Air Force and Navy. This method of power plant mounting was also adopted for commercial airplanes.

(2) Flow of Technology

Since vibration adversely affects functional reliability and service life of aircraft, the significant advances in vibration reduction were quickly picked up and applied in civil aviation. In 1943, the basic requirements for a six-degree-of-freedom vibration isolating engine mounting system were incorporated into the Handbook of Instructions for Airplane Designers (Ref. 5). Similar engine mounting requirements were incorporated into Navy Specification SR-134 in 1944 (Ref. 6). Airplane manufacturers also used this type of engine mounting system in civil airplanes. There was no appreciable time lag between the use of isolation mounting systems in Military airplanes and similar civilian airplanes.

In 1945, Army Air Forces Specification No. 41065 (Ref. 7) was printed which contained vibration qualification testing requirements for equipment installed in airplanes. Twelve revisions of this specification and subsequent similar specifications have been printed through the years up to the current MIL-STD-810 (Ref. 8) which was first presented in 1962.

Since many aircraft manufacturers supply airplanes for both civil and military use, a standardization of procedures used to insure freedom from excessive vibration was issued in Bulletin ANC-12 in 1948 (Ref. 9). This Bulletin was issued by a joint Air Force-Navy-Civil Committee on Aircraft Design Criteria under the supervision of the Aeronautical Board. This work was followed in the early 1950's by the publication of additional vibration control guides and criteria in the Handbook of Instructions for Aircraft Designers. These later guides concerned (1) vibration isolating/absorbing mounting systems for jet engines, (2) minimum clearances between propeller tips and fuselage sidewalls, (3) horizontal tail excitation from the propeller slip stream, and (4) engine cowling vibration.

Following the publication of vibration design and control criteria in handbooks, requirements were incorporated into Specification MIL-A-8870 (Ref. 10) in 1960. During the period from 1967 to 1970, all of the MIL-A-8860 to MIL-A-8870 specifications were reviewed and vibration design and testing requirements for airplanes were removed from MIL-A-8870 and placed in a new specification, MIL-A-8892 (Ref. 11).

An additional means of technology transfer is the Shock and Vibration Symposium, sponsored by the DoD Shock and Vibration Information Center. Current technology in the field of vibration within the U.S. and abroad is presented in technical papers. These papers are published in a Bulletin (Ref. 12) which is a recognized archival journal for the shock and vibration field.

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Technology in vibration reduction is also disseminated in Technical Reports published at the completion of R&D programs. The average time lag from the initiation of R&D to the use of results is generally two to three years.

(3) Civil Aviation Benefits

The use of vibration isolating engine mounts, introduced in 1938, reduced vibration displacements and associated vibratory stresses to one-fourth of the amplitudes experienced without these mounts. This, in turn, provided greater pilot and passenger comfort, airplane functional reliability, and airplane service life.

The developments in vibration reduction all contributed to extending the service life of airplanes which is an important factor in civil aviation.

(4) Subsequent Development

At the end of World War II, an intelligence report on the experience of the Japanese Army Air Arsenal, Tachikawa, indicated that failure to adopt the Taylor dynamic suspension system for engines of 1500 HP and larger resulted in widespread airplane roughness and pilot dissatisfaction in the Japanese Air Force (Ref. 13).

In addition to the engine mounting studies to reduce vibration at the source, advances were made in methods for balancing propellers and rotors (Ref. 14). While methods for measuring and controlling mass balances were well known, Wright Field engineers recognized and resolved the problem of aerodynamic unbalances of propellers. These were controlled largely by assuring geometrically identical blades on multi-blade propeller assemblies.

Subsequent developments in vibration reduction also include work to resolve vibration of horizontal stabilizers of airplanes that were being excited by oscillating pressures in the propeller slip stream and in wakes from the wings. These buffeting problems were worked on analytically and experimentally by NACA at Langley Field. Buffeting was one factor which led to the installation of horizontal tails well above the fuselage, at the mid-fin height and as T-tail configurations. Buffeting also is a factor in the selection of design airspeeds and altitudes for civil aircraft through a Federal Aviation Authority requirement for a 0.5g buffet-free maneuver margin.

With the introduction of relatively large multi-engine airplanes such as the C-119, KC-97, and the C-124, problems arose due to the impingement of pressure impulses from inboard propellers on

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the fuselage sidewall structure and in the case of the XB-36 on wing trailing edge structure. Criteria were developed for propeller-to-structure clearances, and structural detuning techniques were established for the avoidance of structural resonances from periodic types of vibratory excitation (Refs. 15 and 16).

Vibration is inherent in helicopters as a result of necessary cyclic pitch variations in individual rotor blades to achieve desired lateral motion. However, by 1953, vibration levels in helicopters became excessive and the Air Force established a vibration reduction program. The results indicated that structural stiffness increases were needed for rotor pylon attachments, air-frame torsion, and airframe vertical bending. Quality control in the construction of rotor blades was necessary to assure that blades with identical mass, stiffness, and geometry were used. Structural modifications and rotor blade matching, reduced vibration levels, originally at ± 0.3g at rotor harmonic frequencies (4 to 15 cps), one-half which was an acceptable value. A goal was established for helicopters of ± 0.1g for vibration at the pilot's station.

With the advent of jet powered aircraft, the vibratory responses changed from predominantly periodic oscillations to wide-band random responses. By 1955, vibration in bombers and tankers had reached levels that were two to three times as high as the levels that had been established and used in the design and testing of aircraft components. The importance of developing a better approach to the vibration problem was recognized and in the late 1950's, programs with Ramo-Wooldridge provided an analysis of the applications of statistics to random vibration problems. Various fundamental assumptions were checked, and mathematical theories were extended to provide a sound basis for future efforts (Refs. 17 and 18). Immediately following these programs, the NASA initiated programs with the same principal investigators to provide similar results directed toward rocket power d space vehicle vibration problems.

Work has progressed toward establishing needed vibration design and control criteria for compound helicopters, STOL and VTOL aircraft. The Army has remained active in the field of helicopter vibration control in recent years by pursuing technology required for active (Ref. 19) and passive (Ref. 20) vibration isolation systems. Fundamental studies directed at the reduction of vibratory loads input are contributing to the technology as well (Refs. 21 and 22). Dynamic problems, principally vibratory in nature, arise in large diameter rotors and tilting rotor concepts. These problems have been alleviated to a large

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extent as a result of the technology produced by several joint Army/NASA programs (Refs. 23 and 24). Modern methods using high speed computers, indicate that good progress can be made in these areas. Also, high frequency random vibration poses a severe problem in near ground operations of jet powered VTOL aircraft. An accurate method for predicting high frequency random vibration has yet to be developed, although very promising approaches have been studied (Refs. 25 and 26).

(5) R&D Costs

Air Force R&D costs for this technology are estimated to be about $95,000 per year. This includes an average of about 5 man-years/per year of effort. The total Air Force cost of the R&D over a period of 32 years (1936 - 1968) is $3 million. It is estimated that Army and Navy R&D costs for this technology are comparable to those of the Air Force.

D-2. Flutter Prevention*

(1) Early Development

Flutter is a dynamic instability of aerodynamic lifting surfaces occurring in an airplane in flight at a particular speed, called the flutter critical speed, above which the elastic forces of the airplane structure interact with the aerodynamic forces in such a way that violent divergent oscillations occur. In most, but not all cases, the airplane is lost. The first cases of flutter are ascribed to the twin-engine Handley Page 0/400 bomber in 1916 (Ref. 27), the DeHaviland DH-9 airplane in 1917 and the Fokker D-8 airplane during flight testing at McCook Field, Dayton, Ohio, about 1922** (Ref. 28).

Army Air Corps pilots had grave concern about vibration and flutter. For example, the 1934 Air Corps report by W. Stitz at Wright Field on a systematic investigation of 20 Air Corps airplanes (Ref. 30) from September 1932 to December 1933 describes the wing-aileron flutter and rudder-fuselage flutter experienced on the YO-27;

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* Closely allied to the flutter phenomenon are wing torsional divergence and aileron reversal. Since these do not involve structural oscillations or vibrations, they are "static aeroelastic phenomena".

** Earlier a critical problem of wing torsional divergence was encountered in the Fokker D-8 which required extensive stiffening of outer wing panels (Ref. 29).

also, excessive vibration and flutter were reported on the Douglas XB-7, Douglas O-38, Curtiss YA-8, and Boeing YB-9A aircraft. The early prevention criteria used by the Air Corps were based on dynamic balance of control surfaces and control of the natural frequencies and modes of vibration of the aircraft components by rigging and structural stiffening.

From about 1925 to 1940, theoretical developments in non-stationary aerodynamics begun by Birnbaum were being made principally by Glauert (Ref. 31) in England, Kussner (Ref. 32) in Germany, and by Theodorsen and Garrick (Refs. 33 and 34) of NACA in the United States. The procedures developed applied to thin airfoils performing small oscillations in a uniform stream of incompressible fluid. Engineers in the aircraft companies were following these developments and formulating methods of calculating flutter speeds (Ref. 35). Engineering schools such as Massachusetts Institute of Technology, California Institute of Technology, and University of California at Los Angeles developed curricula in flutter, vibration, and non-stationary aerodynamics under the subject matter of aeroelasticity that were taught largely in their graduate schools. Research centers in the graduate schools effectively supported under contract the R&D programs of the Army Air Force and Navy. NACA and the civil aviation industry contributed by their own in-house efforts.

In 1942, the Army Air Forces at Wright Field published AF TR 4798 (Ref. 36). This report extending the work of Bleakney and Loring (Refs. 37 and 38), presented a "three-dimensional" flutter analysis procedure based on energy methods that took into account the vibration modes of the wing and control surfaces. The aerodynamic coefficients, based on the theories of Theodorsen and Kussner, were expressed in non-dimensional form, and numerical values were tabulated for various values of the parameters commonly encountered in practice. This report was extended in 1944 to flutter avoidance of control surfaces with spring tabs by the Air Force (Ref. 39).

(2) Flow of Technology

The Air Force report 4798 on flutter analysis procedures was accepted as a handbook for making flutter analyses by military and civil aviation, and is still commonly used for preliminary design studies. Because of its wide acceptance, this is considered a significant advance in flutter prevention methods. In order to implement dynamic analyses, data were needed on the vibration modes of aircraft. To obtain the necessary data, Air Force personnel conducted vibration tests . contractors' plants

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as part of aircraft acceptance inspections. This developed the well known "ground vibration test" which has become an important step in the flutter clearance procedure. The flutter analysis and test methods were placed in the Handbook of Instruction for Aircraft Designers (Ref. 40) and Air Force Specification 1817 (Ref. 41). The Navy also published specification NAVAER 55-23 (Ref. 42) requiring three-dimensional flutter analyses that followed Air Force practice.

(3) Civil Aviation Benefits

The three-dimensional flutter analysis procedures developed by the Air Force in Ref. 36 for military aircraft were adopted and used by civil aviation. In a Civil Aeronautics Authority Publication (Ref. 43), an outline of acceptable methods of vibration and flutter analysis for commercial aircraft air worthiness requirements is given that was based on the Air Force methods presented in Ref. 36. These procedures were used in design of all civil aircraft for many years and are still used in many instances for flutter analyses in the subsonic speed regime. In addition, Air Force methods of acceptance including ground vibration test and flutter modeling test technology as well as flutter trend data obtained under Air Force programs have been applied in design and verification of flutter safety for many commercial transports such as the Douglas DC-9 and Boeing 727.

(4) Subsequent Development

In the mid 1940's the introduction of swept wings led to an investigation of the effects of wing sweep on flutter. These results are presented in Ref. 44 for tests at low, subsonic speeds conducted in 1946 and in Ref. 45 for tests up to Mach number 0.94 in 1947.

In the late 1940's and early 1950's the use of external stores such as tip tanks and pylon suspended stores resulted in several flutter incidents. In 1953 investigations were conducted to provide flutter prevention design criteria (Ref. 46) for both straight and swept wings with stores.

Beginning about 1950, aircraft powered by jet engines achieved flight speeds in the transonic speed regime. Moreover, the use of lower thickness-ratio airfoils resulted in more flexible lifting surfaces and a susceptibility toward flutter. Unfortunately, methods required to predict the transonic unsteady aerodynamic forces needed for flutter analyses were not available. An experimental approach utilizing flutter models in wind tunnels was initiated in 1952 to define variations in flutter speed through the transonic speed range for various wing planforms. Results obtained in the transonic wind tunnel are given in Ref. 47 for straight, 45 degree swept and delta

wings. Results showed reductions in the flutter speed at transonic velocities, thus requiring higher structural stiffness to avoid flutter. Transonic flutter speed correction factors were defined and used on fighters (F-100, F-105, F-106) and bombers (B-52, B-58) to establish the required 15 percent margin of safety in velocity at both constant altitude and constant Mach number.

The success of the transonic flutter model tests inspired the development of flutter models that directly defined flutter safety of an aircraft. The use of a series of wind tunnel flutter models remains the practice today as an important step in the determination and placement of the flutter boundary for aircraft.

With flight speeds penetrating further into the transonic speed regime, mass balance being eliminated on control surfaces to reduce weight and more complex airplane configurations occurring due to the use of external stores on wing tips and pylons, flight flutter testing of the full scale airplane became increasingly important because these trends caused uncertainties in both flutter analyses and wind tunnel flutter model tests results. Flight flutter testing procedures were under development in the 1940's, but this type of testing matured as a practical technique in the 1950's when tests on the then unconventional and high speed airplanes, the Northrop F-89 and Convair F-92, became necessary (Ref. 48). Continuing aircraft design complexities finally made flight flutter testing a requirement for all airplanes (Ref. 10).

During 1962-1963, the Air Force and NASA investigated the phenomenon known as "panel flutter" which had been experienced by supersonic aircraft such as the X-15, A3-J, T-38, F-101, and was a major structural design consideration for the X-20 Dynasoar. Programs were set up to obtain panel flutter data in wind tunnels under carefully controlled conditions from M=1 to 10 (Refs. 49 and 50). The results have been used to assess potential problems for the F-111, B-1, and supersonic and hypersonic aircraft. A series of design charts were developed to aid designers in preventing panel flutter (Ref. 51). This work was incorporated in Specification MIL-A-8870A (Ref. 52). NASA contributed in the panel flutter area with reports such as Ref. 52, and others on various parametric studies including the effects of aspect ratio and panel stresses.

Since 1963 work in non-stationary aerodynamic research has been underway that provides methods for predicting oscillatory airloads for complex aircraft configurations to assure, in the design stage, that flight vehicles will be safe from flutter. These procedures are based on aerodynamic lifting surface theory and include the "kernel function" method and the "doublet-lattice" method for the subsonic speed range and the "Mach box" method for the supersonic

speed range. Significant contributions were made by NASA scientists (Ref. 54) in development of the kernel function method for planar surfaces. In 1965 these kernel function methods were extended to non-planar surfaces (Ref. 55) and in 1968 to control surfaces (Ref. 56). The doublet-lattice method was developed to a high degree by Albano and Rodden (Ref. 57). Development of the supersonic Mach box method for intersecting planar lifting surfaces was accomplished in 1965 (Ref. 58). These modern theoretical methods, relying heavily on large computers, provide design guidance for prevention of flutter instabilities on lifting surface configurations with control surfaces, on intersecting surfaces such as T-tails which have aerodynamic interference effects, and on swing wing-horizontal tail combinations where mutual aerodynamic interference is significant. There has been extensive use of the kernel function and doublet-lattice subsonic methods as well as the Mach box supersonic method by the aircraft industry for both military systems and commercial transport designs.

(5) R&D Costs

Air Force R&D costs for this technology are estimated to be about $310,000 per year. This represents an average of about 7 1/2 manyears/per year of effort. The total cost of the R&D over a period of 32 years (1936-1968) is about $9 million.

D-3. Airplane Acoustics

(1) Early Development

The primary sources of aircraft noise are the propulsion system and the aerodynamic noise associated with flight through the atmosphere. The propeller was first studied as a source of noise by Gutin in 1936. Limited propeller noise studies were also conducted at NACA in the late 1930's. Initial engineering approaches to control the internal aircraft noise began in the military when, in 1940, the Army Air Corps Materiel Center, Wright Field, Dayton, Ohio, requested the establishment of a research project for studying methods of reducing noise in long range bombers. This research with Cruft Laboratory, Harvard University, led to the publication of a report entitled, "Principles of Sound Control in Airplanes" (Ref. 59). The report presented methods of estimating interior noise levels in aircraft and procedures for designing acoustical treatment

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in aircraft. Throughout the 1940's, the Air Force, using commercially developed fine fiber materials, systematically devised sound-proofing systems composed of trim cloth, blanket, and septum which provided maximum noise attenuation with a minimum weight penalty (Ref. 60).

Propeller noise research at NACA included defining near and far field propeller noise and relating this noise to propeller operating parameters and conditions (Ref. 61).

Aerodynamic noise was recognized as a source of noise in the 1940's and schemes for estimating its effects on internal noise were published in 1952 (Ref. 62).

With the introduction of jet and rocket powered aircraft, acoustic problems were magnified. Effort was expended to define this noise and its effects on equipment, aircraft structure, and subjective reaction of crew members to the noise. A rational approach to noise control encompassing the technology to that date is included in Reference 63. The classic paper dealing with jet noise was published by Lighthill (Ref. 64).

Airplane propulsion noise reached levels in the middle 1950's which resulted in structural fatigue. Increased emphasis was consequently placed on the prediction of the near field jet noise. Simplified methods were developed in the form of charts, graphs, and equations to predict noise from propellers, jets, rockets, and the turbulent boundary layer (Ref. 65). Also, methods were included to estimate the internal noise of aircraft. Contributions were also made by NACA and the Royal Aircraft Establishment in England.

With increased flight speeds, aero-acoustic excitations including boundary layer pressure fluctuations, base pressure fluctuations, wakes from projections, cavity resonances, oscillating shocks, and separated flows become of increasing importance as sources of internal noise and as structural loads.

The Air Force investigated the noise fields of STOL and V/STOL systems (Ref. 66); flow induced oscillations in bomb bays were also investigated (Ref. 67). Noise investigations for application to a quiet airplane and a quiet helicopter (OH-6) were initiated by ARPA and resulted in the Army YO-3 aircraft. The Air Force developed aural detection criteria for the low-speed, low altitude covert Quiet Aircraft and has provided a guide for predicting the aural detection of these aircraft (Ref. 68).

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Government facilities have been used in developing with Industry noise absorbent treatments for aircraft nacelles and structures near the engine effluxes.

(2) Flow of Technology

The work by the Cruft Laboratories was used in writing Army-Navy Specifications AN-S-32, AN-S-33, and subsequently MIL-S-6144 and was also incorporated in 1954 in the Air Force Handbook of Instructions for Airplane Designers. The theoretical and experimental investigations conducted by NACA in the 1940's were used to establish fuselage-propeller tip clearance criteria which were incorporated into the later editions of HIAD in terms of internal noise criteria as defined in MIL-A-8806, Acoustical Noise Levels in Aircraft and structural criteria as defined in MIL-D-25571, Data for Airframe Subsystems. Airplane acoustic technology advances by the military and NASA are disseminated in technical reports and papers. Participation in the noise research and sonic boom panels of the DoT Interagency Noise Abatement Program by DoD and NASA contribute to technology transfer.

(3) Civil Aviation Benefits

R&D conducted and sponsored by the Military Services and NASA indicated the methods by which civilian aircraft and power plants could be modified from a noise control viewpoint. Lightweight, efficient soundproofing systems for aircraft appear to have been first developed by the military, and were applied to crew and passenger compartments of civilian aircraft. The development testing of sound absorbing treatments for engine nacelles in military and NASA facilities has been of substantial benefit to civil aviation. The military interest in Quiet Airplanes has resulted in development and design methods and test techniques which, although not directly applicable to civil aviation, contribute significantly to the technology of quieting the several noise sources in aircraft.

(4) Subsequent Development

Methods for determining airplane internal noise levels were updated utilizing current near-field measurements and modern computer techniques (Refs. 69 and 70).

NASA and Industry conducted research on noise generation, propagation, attenuation and subjective response related to noise abatement of large subsonic aircraft (Ref. 71).

Research in sonic boom phenomena is primarily conducted by NASA and comprises wind tunnel experiments up to M = 4.5 which

correlate boom signature with airplane configurations. NASA is also conducting flight experiments for sonic boom research (Ref. 72). The Air Force conducted wind tunnel experiments up to M = 2.5 to obtain boom signatures on various delta wing configurations. The FAA collected field data concerning overflight boom signatures caused by military aircraft.

(5) R&D Costs

Research and development cost in the area of airplane acoustics has amounted to approximately 200K per year since 1959. The national research and development cost in the area of noise abatement in 1971 was in excess of 45 million dollars. Industry expenditures are estimated at $20 million, NASA at $15 million, and DOD, DOT-FAA at $10 million.

D-4. Sonic Fatigue

(1) Early Development

In the 1940's fatigue failures due to aero-acoustic pressures generated by propellers occurred in fuselage side walls and wing structure of aircraft such as the C-119, KC-97, and XB-36. These excitations were periodic and in all cases failures resulted from structural resonances. Detuning the structure by stiffening sufficed as a fix. With the use of the jet engine, the noise energy radiated from the jet efflux produced very high sound pressure levels on adjacent structure. The excitation was broad band random in nature. Extensive fatigue failures were produced very rapidly. This problem was termed "sonic fatigue".

In 1956, sonic fatigue failures in Air Force bomber airplanes were sufficiently numerous as to constitute a severe maintenance burden. Aircraft were experiencing 12 hours down time per airplane flight hour due to repair of sonic fatigue damage alone. The Air Force initiated action to resolve the overall sonic fatigue problem by planning and accomplishing (1) early in-house programs to evaluate fixes for production aircraft, and (2) longer-range exploratory development efforts to provide new design criteria for future aircraft. This in-house work covered a four-year period, from 1955 to 1959, and included planning and directing ground sonic fatigue tests and evaluating fixes for operational aircraft (Ref. 73). Over 2,000 sonic fatigue failures resulted from a representative ground test. In the period from 1955 to 1957, an average of $10,000,000 per year was spent on retrofits. In 1958, costs from sonic fatigue aircraft were $30,000,000. In 1959, sonic fatigue difficulties on aircraft were under improved

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engineering design control. The costs for sonic fatigue repairs were reduced by a factor of 6 and critical problems in the operational commands were largely relieved.

Technical knowledge and original criteria for reduction and control of sonic fatigue were published in technical papers and reports (Ref. 74). This included an evaluation of sonic fatigue failures on service aircraft. The characteristics of the noise environment and its effects on structure were defined and a criterion for noise levels greater than 140 dB was established as being critical from a sonic fatigue viewpoint. Initial investigations in the behavior of structures under high intensity acoustic loading were undertaken. A development and proof test cycle was established as part of requirements for structural fatigue certification programs (Ref. 75).

During this time period, NASA investigated the occurrence of various types of structural failures in aircraft which were attributed to acoustic excitation. Experiments were conducted by NASA to determine the response and sonic fatigue characteristics of flat and curved aluminum panels (Ref. 76).

In 1958 the Air Force initiated the design and development of a large acoustic test facility at WPAFB. This facility was planned for research, development and proof tests on components and full-scale sections of flight vehicles (Ref. 77).

(2) Flow of Technology

The attainment of sonic fatigue resistant flight vehicle structure was first accomplished by a long and expensive development cycle involving design, laboratory tests, redesign, and retrofit. This time consuming, expensive cycle was reduced through the use of design charts (Ref. 78). The Douglas Aircraft Company originally developed design charts for permissible acoustic loading of skin-rib aircraft structure. Subsequently, the Air Force extended this work under contract with Douglas to include skin-stringer construction with bonded skin doublers, welded skin-stringer construction with bonded skin doublers, welded skin-stringer structure, honeycomb, bonded-beaded, and corrugated panels. These charts were made available to industry at large. In general, most of the technology developed is put to use as soon as it is required in the solution of a noise or sonic fatigue problem on an operational aircraft. There are two primary reasons for this minimum time lag between development and use: (1) the information is developed because of a need, and (2) normally tests are conducted to show the applicability of the technique or method.

The studies and design information developed in the above programs have culminated in the sonic fatigue specification MIL-A-8893 (USAF) (Ref. 79). This document outlines the design requirements for the prevention of sonic fatigue in aircraft. It also outlines the test requirements that necessitate the sonic fatigue proof testing of aircraft.

(3) Civil Aviation Benefits

The design criteria developed for the prevention of sonic fatigue on military aircraft are fully applicable to many types of civilian aircraft and in particular to transports. For example, criteria and design modifications which were developed for structural components of the KC-135 Tanker (engine pylons, wing trailing edges, and fuselage) found ready application on the Boeing 707 civilian transport aircraft.

The advanced performance characteristics of military aircraft apply more stringent requirements on sonic fatigue design which benefits civilian application by providing proven information. These facts are well recognized by the aircraft industry which has made extensive use of available sonic fatigue design information. Since a large part of the research and development work in this field is conducted by industry under government sponsorship, contractors also benefit from the experience provided.

In addition, the acoustic test facilities of the Air Force, NASA, and Industry with their established capability, have contributed to the reliability and maintainability of civilian transport aircraft.

(4) Subsequent Development

An effort was undertaken with Lockheed to refine and extend the design charts (Ref. 80). In addition, initial efforts were made to study the effects of the combined environments of noise and temperature. The sonic fatigue characteristics of filament composite structures and the design and sonic fatigue resistance of composite joints have been investigated (Refs. 81 and 82).

In 1965, the Air Force's Sonic Fatigue Facility became fully operational and capable of simulating jet and rocket engine noise effects on full-scale vehicles or structural components at sound pressure levels which are equal to or higher than those experienced in the service environment. This makes possible accelerated acoustic fatigue tests on flight vehicle structures which yield fatigue life data far earlier than the accumulated fatigue life data acquired in service. Numerous experiments were completed which included systems such as C-141A, F-111, A6A, F-4, EA-6B and F-15

aircraft, Athena missile and bioacoustics tests, such as the Low Frequency Exposure-Human Tolerance Study for the Apollo Program. The tests performed on F-111 and F-15 components involved simultaneous application of noise and heat.

(5) R&D Costs

Research and development costs per year since 1955 amounted to about $0.5 million including contracts and salaries. It is estimated that the cost to the civilian sector would have been a minimum of $0.25 million per year if the R&D investment had not been made by the military. In addition, the potential economic losses to the civilian sector would involve a doubling of the maintenance time on affected aircraft and consequent loss of flight hours.

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SECTION II-E
VEHICLE EQUIPMENT

In this section of Air Vehicle Technology, three significant advances are described: (1) Landing Gear; (2) De-icing - Anti-icing; and (3) Pressurized Aircraft. These developments were essential to the development of military aviation. They were also essential in the same degree to civil aircraft. None of these involve directly the principles of flight; they are contributions to aeronautics from the broad areas of engineering involving the ingenuity of mechanical engineers, thermodynamicists and physicists and the doctors of aviation medicine. The early landing gear developments were initiated in the civil sector; de-icing and anti-icing as well as the pressurized airplane appear to have been first developed by government research; in the first case by NACA about 1928, in which tests were conducted on wing icing in a "refrigerated" wind tunnel, and in the second case by the Air Corps with their pressurization experiments in the 1920's.

E-1. Landing Gear

(1) Early Development

From the early days those involved in the development of aircraft recognized the need for an adequate means for ground handling, take-off and landing of aircraft. The undercarriage, alighting gear or landing gears designed for this purpose rapidly became a very important part of the flight vehicle. No mechanism has required a greater mechanical ingenuity or has resulted in more mechanical complexity. An aircraft system design is always a matter of carefully matched compromises but as airplanes have evolved, the landing gear seemed to have called for more compromises than any other part of the structure. The main function of the landing gear is to dissipate the energy of descent during landing without undue shock to the aircraft or its occupants and to provide a reasonable carriage on which an aircraft can taxi, take-off and land. Since the landing gear is used for a relatively short part of the aircraft life and is simply an undesirable weight carried at the expense of payload, the designers have endeavored to reduce its weight to a minimum. By the year 1925, many conventional landing gear configurations had evolved such as a pair of main wheels and a tail wheel or simply a leaf-spring tail skid. Some special deviations from this practice had already been invented such as multi-wheel landing gear used in the Handley Page airliners of the early twenties, the retractable landing gear such as used on the Dayton Wright experimental pursuit. The use

of oil damping to restrict rebound was used first by the French engineer Esnault Pelteire in 1908 and an early form of oleo (hydraulic shock absorbing strut) was fitted to the experimental British BE-2 in 1912. The next ten years of development were refinements of the conventional gear with partially retractable and completely retractable gears under consideration. As aircraft landing and take-off speeds increased, tricycle gears began to appear. With the increase of aircraft gross weight in the early forties, landing gear wheels went up to 110 inches in diameter such as for the first XB-36. However, the inertia and drag loads at landing generated in getting the wheel up to speed created serious problems with the whole landing gear structure. And, even though wheel side flaps to generate wheel turning before landing impact were invented, these did not increase the wheel rotational speed sufficiently to reduce loads. At this point, multiple wheels were introduced on the B-29 and the B-36 aircraft. The military program directors for the B-36 recognized the need for a new landing gear design and a gear using tandem dual wheels (four 56-inch wheels) was developed for this large aircraft. Other technological advancements were made. These were nose wheel steering, nose gear shimmy dampers, and anti-skid devices. An additional significant advancement for large aircraft of the 700,000 pound class, was high flotation. This brought about the development of landing gear designs using multiple, 4-wheel bogies.

As aircraft began to develop to higher speed, aerodynamic cleanness became a serious problem and landing gears were streamlined by the application of aerodynamic fairings. Tires were shaped so that smooth contours were incorporated. The landing gear, however, was an obvious source of drag. One aircraft, the Sperry Messenger, was tested in a NACA wind tunnel and its fixed landing gear was found to account for 40% of the drag. Many set about to improve this drag problem and there were many opinions voiced pro and con regarding retractable landing gear possibilities. Many of the conservative engineers in aircraft design argued that the retractable landing gear would be heavier, less reliable, more difficult to maintain and could cause a longitudinal stability and control problem in flight. To make the argument more convincing, aerodynamicists were busy designing fairings (with the help of wind tunnels) to reduce landing gear drag. Nevertheless, in June 1921, three XPS-1 (Experimental Pursuit Special) were built by the Dayton Wright Company on a $90,000 contract signed by the Air Service Engineering Division at McCook Field, Dayton, Ohio. In these aircraft, the Air Service was interested in performance so the retractable landing gear was one more experiment in continuing the struggle toward high speed. The XPS-1 aircraft performance was improved by the retractable

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landing gear. In 1921, Alfred Verville, a McCook Field engineer, designed an Army Air Corps racer, the R-3, with major advances such as a low monoplane wing, improved streamlining and retractable landing gear. The first military application was to the Grumman XFF-1 fighter for the Navy in 1931, and to the Boeing XP-29 for the Army Air Corps in 1934. This latter aircraft actually incorporated a landing gear where the wheels retracted backwards about halfway into the wings. This approach to designing a less complex gear system resulted in reducing the landing drag by a factor of two. Shortly after, partially retracted gears such as were incorporated in the C-47 were used. This resulted from wind tunnel tests indicating that fairing and smooth tires helped to reduce drag. The Army Air Corps conducted tests with streamlined tires and showed that drag coefficients (C_D) of landing gears were approximately as follows:

Landing gear down	$C_D = 1.16$
Landing gear swung aft	$C_D = 0.66$
Fairing behind partially exposed wheel	$C_D = 0.33$

(2) Flow of Technology

The close matching of an aircraft landing gear to the airplane made it necessary that each design received careful engineering attention to solve the problem of low weight, low drag, reliability and minimum maintenance. The transfer of technology is not clear in this type of engineering since the personnel involved in this type of activity were careful to be well informed on all types of landing gear designs and the resulting experience of these when used. For example, the first civilian applications of the retractable landing gear were being incorporated in 1930 into the Boeing Monomail Model 200 which first flew in May 1930 and later, in the middle thirties, into the Douglas DC-2 1/2 and DC-3. This technology continued to be introduced into all aircraft. In the early forties, the Army Air Corps, Dayton, Ohio, set up landing gear and tire testing facilities as well as design requirements for landing gears, wheels and tires. These requirements together with test data flowed into civilian aviation. In fact, the landing gear, wheel and tire testing was being accomplished for military airplanes but the data obtained helped to support the whole aviation industry. The Industry Tire and Rim Association pursued the necessary efforts as a coordination and planning group. The Military Services were full-time members of that association

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and this group relied on the results of testing accomplished at Wright Field. In the fifties, the landing gear, wheel and tire industry began to build their own test facilities and accomplish the necessary R&D particularly that needed to meet the rapidly growing demand of civilian aircraft.

(3) Civil Aviation Benefits

The major benefits to civil aviation came from specific technological efforts to improve landing gears for high speed aircraft. One item was the nose and/or tail wheel shimmy which had been an annoying problem with nearly all aircraft since the DC-3. However, it was not until the experimental XB-49 Flying Wing was destroyed on the ground by catastrophic nose wheel shimmy that the problem was considered in depth. The Air Force Aeronautical Research Laboratory, under Professor Moreland, developed the basic theory and analysis which is used throughout industry today in predicting and preventing the onset of shimmy. Another area of much concern was the development of the anti-skid system. This technological effort was initiated in the late 1940's and the results added greatly to the safety of commercial aircraft.

(4) Subsequent Development

Other major developments for improving the take-off and landing of aircraft were in high flotation landing gear and replaceable tread tire.

As aircraft speeds increased, the more slender fuselages and thin wings made it difficult to retract landing gears. Therefore, thinner tires were being developed and these involved higher and higher tire pressures. This in turn, decreased the effective footprint of the aircraft wheel and created higher pressures on the runways. Such aircraft, particularly the military ones, could not operate on "soft" landing strips. The use of multiple wheels eased the runway loading problem. However, it by no means solved this problem completely. One possible answer to the problem, then referred to as flotation, was to increase multi-wheel installations. A Boeing 707 was fitted with a 20 wheel landing gear for soft field experiments. It was shown that with extra wheels mounted adjacent to the normal wheels, the aircraft could be operated from ground barely able to support a motor car. The United Kingdom led in this effort by their earlier work with the Short Belfast military transport. The main gear on this aircraft comprised a compact 8-wheel bogie unit which retracted into a blister on the side of the fuselage.

An Air Force development was also an 8-wheel bogie used on the B-58 supersonic bomber. This technology then soon found widespread use on larger civilian airliners such as the Comet, Caravelle, Convair 880, Boeing 707 and 720 and the DC-8.

The Air Force is presently developing a new aircraft tire concept which will allow the tire to be retreaded without removing it from the aircraft. This replaceable tread tire has already been tested on a small (3000 pound) aircraft and is now in development for the C-130 size aircraft. It has been estimated by the Air Force Logistics Command, that savings would be in the order of one million dollars per year for the C-130 fleet. When applied to commercial aircraft and possibly even automobiles, large savings in maintenance should result. This effort is the only known development of replaceable tread tires.

(5) <u>R&D Costs</u>

The early efforts in the landing gear began with an estimated $5,000 in R&D costs in 1921 to support the XPS-1 Dayton-Wright airplane. In the early thirties, some estimated $200,000 were expended for landing gear and wheel R&D by the Air Corps. Technological efforts to improve and develop landing gears for airplanes were integrated with the total R&D cost of each particular aircraft program. The Military Services undertook R&D programs for various components of the landing gear such as struts, wheels and brakes, tires and retraction mechanisms (such as the ball bearing screw jack). The retraction gear for the landing gear system was so closely integrated with the airplane design that it was considered within the R&D efforts of the airframe development. One of the most unthought of but yet significant developments in landing gear technology was the metering pin designed for hydraulic shock absorbing landing gear struts. In 1929, under the direction of Mr. T. dePort, in the Aircraft Branch, Army Air Corps, the metering pin design was invented and developed. This metering pin, different from others that had been invented, was designed to restrict the flow in the hydraulic orifice of the shock strut. The pin closed the orifice until the full load in the tire was developed, then controlled the orifice to keep the tire compressed to a constant nearest maximum load. Therefore, this regulatory hydraulic mechanical device became very useful in the action of the landing gear when absorbing loads. The development was incorporated in landing gear struts by the Bendix Corporation and sold to aircraft industry for use by civilian and military aircraft. The cost of this development was estimated at about $10,000. However, the value of the development for civilian use amounted to millions of dollars.

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As aircraft size, speed and take-off and landing speed increased, much effort was incorporated into equipment for this purpose. Most of the technology work (R&D) was accomplished within the R&D dollars of the system program. For the C-5A, the cost element of the landing gear for the RDT&E in subcontract dollars is estimated at 8.2 million dollars for the main gear and 2 million dollars for the nose gear.

E-2. De-icing and Anti-icing

(1) Early Development

Work on de-icing/anti-icing of external surfaces (wings, empennage struts) began in 1928 (Refs. 1 and 2) at NACA, Langley, as a result of Army Air Corps and Navy requests. The subject had always been of interest; however, the early commercial aircraft and the Army experiences in flying the mail apparently crystalized the need for work.

Between 1928 and 1931, flight and refrigerated wind tunnel tests had identified the primary forms of ice, the ambient temperature and humidity conditions in which ice could be expected to be encountered, the effect of ice accretions on aircraft and directions that should be further explored. For example, NACA had suggested heated leading edges and wind tunnel/flight test work performed by Cornell University with assistance of B.F. Goodrich Company and National Air Transport, Incorporated, under sponsorship of the Daniel Guggenhein Fund for Promotion of Aeronautics had established the potential of pneumatic de-icer boots for leading edges (Ref. 3). Further, the definition of the temperature and humidity (visible moisture) range enhanced the meteorologist's ability to predict icing conditions and this same information, together with an outside air temperature indicator, enhanced the pilot's ability to avoid ice in flight.

During the remainder of the 1930's, the work was on further definition and refinement of earlier efforts. This included further meteorological definition (Ref. 4), tests of industry developments of possible solutions established by the early work such as pneumatic de-icer boots (Ref. 5) and further definition on specific aircraft component ice prevention problems such as propellers (Refs. 6 and 7) and windshields (Ref. 8).

The major payoff from this early work had been in the direction of de-icing equipment; pneumatic inflatable boots for wing and empennage leading edges, alcohol spray for propellers, alcohol spray plus windshield wipers for windshields, and in some cases, alcohol spray for carburetor icing with some use of engine heat

for carburetors and electrically heated airspeed sensing probes. De-icer boots appeared both on military and civil aircraft about 1935, on the Douglas XB-18 and DC-2. These de-icing techniques did allow operation in icing conditions; however, they involved many disadvantages and problems. For example, non-operating pneumatic inflatable boots increased wing and empennage drag by 10 to 15 percent, with 100 percent increase during operation; de-icing systems were heavy and not always effective. The need for more efficient ice protection was fully recognized in the late 1930's and an extensive effort spearheaded by NACA was undertaken to develop the necessary technology. It should be pointed out that hardly any theory, practical information, or even methods of measurement necessary to obtain information on the droplet size and liquid water content of icing clouds existed. This information was necessary to allow prediction of the trajectory of droplets in relation to leading edges and hence, the leading edge area that required protection and the amount and distribution of heat required. Further, heat transfer theory had never been applied to the configurations and constraints of aircraft, except for engines.

This extensive effort resulted in the modification by Lockheed Aircraft Corporation of a 12A airplane incorporating an exhaust gas heated wing (Ref. 9), and the publication, starting in 1942 and extending into 1945, of a series of 18 NACA sponsored reports by University of California. These reports, "An Investigation of Aircraft Heaters" covered all foreseeable heat exhanger and heat transfer component design problems associated with heated wings. In 1942, the Ice Research Base was established at Wold Chamberlain Field, Minneapolis, Minnesota with Northwest Airlines as the operating contractor under sponsorship of NACA, the Air Corps and Navy. Application of the heated wing technique was further explored through military sponsored design, modification, and flight test efforts on two Army and one Navy aircraft (Ref. 10). This increased military involvement resulted in further definition of the heated wing solution to icing (Ref. 11). Effort toward a theory for the formation of water droplets in nature was pursued by Langmuir and Blodgett of the General Electric Company and the results of this theory applied to leading edges under Air Corps sponsorship (Ref. 12).

Propeller ice protection had advanced through NACA/military sponsored developments to an electrically heated boot on the leading edge with electric power provided by a propeller shaft driven generator. A transparent electrical conduction coating had been developed by Pittsburgh Plate Glass Company for use in improving the

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fireproofing of aircraft windshields by keeping the vinyl layer warm and hence, more resistant to shock loads. This method of heating proved readily adaptable to windshield anti-icing and was almost universally adapted to new military and commercial aircraft; however, the combinations of thermal and pressure loads created a breakage problem which resulted in development of improved installation criteria and theory of heated glass failure (Ref. 13). The application of heated wings to many late model reciprocating engine powered aircraft revealed that in many cases, especially those with turbosupercharger installations, the use of engine exhaust gas heat exchangers resulted in a significant range penalty to the aircraft when anti-icing was required (i.e., the engine had to be operated at off optimum conditions to produce the heat required). This resulted in the use of combustion heaters for many aircraft of the late 1940's (B-50, C-97, Boeing 377, Douglas DC-6).

The advent of gas turbine engines changed the ice prevention problem considerably. Mechanical complexities eliminated the use of exhaust gas heat exchangers which was completely offset by the ability of the engine compressor to provide directly compressed air at sufficient temperature and flow to become a source of heat for ice protection. Further, since these engines, together with the use of cabin pressurization, moved the normal aircraft operating altitudes to well above the high probability icing levels (0 - 20,000 feet) the frequency and direction of use of ice protection was reduced to primarily penetration/landing and take-off/climb-out conditions. Gas turbine engines were in a sense an unknown in terms of their susceptability to blockage or damage as a result of ice.

Early jet engines were of too low a pressure ratio to provide sufficient air at a temperature for wing anti-icing; consequently, considerable work was done on cyclic electrically heated boots - the only application being the F-94D aircraft (Ref. 14). The axial flow turbojet was suspected to be sensitive to icing in early service experience and this sensitivity was verified (Ref. 15) followed by development effort to define, implement and then verify these solutions (Refs. 16 and 17).

On 8 June 1951, a flight of 16 F-84E's tried to penetrate a cloud formation in the vicinity of Indianapolis, Indiana. Eight of these aircraft crashed; seven of them due to ice blockage of the

inlet screen installed on the J-35 engine (Ref. 18). This not only spurred military concern with engine ice protection, but established a priority need for an ice detector that would warn the pilot or automatically activate ice prevention equipment. A development program on an ice detector resulted in an acceptable device in December 1954, which was then incorporated into nearly all Air Force turbojet aircraft and into the Navy's PY/6M.

As mentioned previously, most of the flight test development work was conducted through the Ice Research Base at Minneapolis. In 1948, Smith, Hinchman and Gryllis of Detroit, Michigan was the successful contractor and the activity was changed to the Aeronautical Ice Research Laboratory at Willow Run Airport, Michigan, until 1955 under Air Force and Navy sponsorship. In the late 1940's, the advantages of a natural icing facility were implemented by the Navy through the use of the conditions existing on the top of Mt. Washington in New Hampshire. During the 1946-1947 winter, a Phantom aircraft was tested and in 1950, the Air Force joined with the Navy in this effort on Mt. Washington with Smith, Hinchman and Gryllis as the operating contractor. Many aircraft components including helicopter rotors and engines (J-33, J-34, J-47, J-73) were subjected to icing development and proof tests at this facility until 1967 when it was closed.

The flight test work at Aeronautical Ice Research Base had gradually transitioned from flight in natural ice to the use of water-spray equipment installed on the test aircraft so that only the component being tested was subjected to the spray. When the contract with the Base was terminated in 1955, the flight testing was continued "in-house" by the Military Services. Before termination, the use of tanker aircraft with a spray rig at the end of the refueling boom had been preliminarily explored utilizing a KC-97 tanker. During the ensuing years since 1954, ice and rain simulation tests have been conducted behind tankers such as the KB-29, KC-97, C-123, C-130 and KC-135. Several refinements in the spray rig to obtain droplets and distribution closer to those of natural conditions were made.

(2) Flow of Technology

In the very early days, the technology was transferred through the publication and distribution of reports. Later, during the 1930's, 1940's, 1950's, and 1960's, initial technology flow was nearly immediate since the designer or manufacturer was one of the participants in the test or investigation. Further, reports of tests and investigations were published and distributed to industry. In the event the test or investigation involved a proprietary item,

other industrial segments were not informed for approximately one year. Due to the nature of the icing problem and the need for efficient, adequate solutions, a significant advance found its way almost immediately into the aircraft industry associated with military aircraft and, consequently, civil aircraft. The DC-6 for example, was quite comparable in ice prevention equipment to the B-50. Further, there were symposia held and papers published through engineering societies covering the topics within but a few months to a maximum of one year of their occurrence. Examples of this are (Refs. 19 and 20) which represent the latest information on the subject of aircraft icing and icing flight testing.

(3) Civil Aviation Benefits

Civil aviation has benefited directly from this R&D effort. The airframe manufacturers have utilized all icing and ice prevention information with the result that schedule delays and/or flight cancellation due to in-flight icing or the pre tion of in-flight does not occur except as a result of an aircraft equipment failure. Essentially, all transport category aircraft since and including the DC-3, have employed ice protection equipment.

(4) Subsequent Development

Relatively little R&D work has been done since 1958. However, icing flight tests of new aircraft as required are carried out by the manufacturers in conjunction with the Air Force Flight Test Center. Between 1954 and 1958, most effort was toward refining analytical methods and providing droplet trajectory data for more modern airfoil shapes. Probably the most significant advances since 1958 have been in the area of design and operational analysis (Ref. 21). For example, analysis of routes and altitudes flown indicate ice accretion only during penetration, or holding, landing, and take-off flight phases. If the air speeds involved during these phases are such that ice will not accumulate on the large radius portions of the wing leading edges so that there is very little, if any, reduction in wing lift at normal landing speeds, then wing anti-icing is not required. Further, if any aircraft controllability can be shown to be maintained under these same flight phases with icing of the empennage, then ice protection for that part of the aircraft is not required.

Recent industry effort has gone into prediction and design factors associated with new configurations (Ref. 22).

(5) R&D Costs

The R&D investment in the de-icing and anti-icing area appears to be in the neighborhood of 35 million dollars spread mainly from 1928 to 1958. Of this amount, roughly 31 million dollars came from the government sector. Only some rough cost data was available from some aspects for the military sector. This information is as follows:

Spray Rigs and Flying Costs of Tanker and Test Aircraft	$ 1.2
Operation of Mt. Washington Facility	14.
Facility Investment in Mt. Washington	4.
Operation of Facility at Willow Run (Smith, Hinchman & Gryllis/Univ. of Michigan)	3 5
Military Share to Wold Chamberlain Facility	.3
Military Design, Analysis Criteria Studies of Aircraft and Components	2.
	$25. million

The NACA effort in wind tunnel and flight test support facilities is estimated at 2 million dollars, with an additional 2 million dollars toward contractor supplied hardware and investigations. The NACA "in-house" investigational, analytical, and test type engineering effort is estimated at an additional 2 million dollars.

It is estimated that the civil sector R&D effort was around 4 million dollars. This is based on the contributions made and the nature of these contributions. The areas considered in this estimate were primarily the development of pneumatic wing de-icer boots, electric propeller ice protection, turbojet engine ice protection, flight tests of aircraft ice protection systems for civil aircraft, and the analysis and design effort toward new concepts of civil aircraft.

Several factors affect the cost of the R&D effort that would have been required by the civil sector if no government sector effort

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had been made. These factors, in general, are: the change in cost of a given effort as a function of calendar time, the calendar timing of the government effort on aircraft icing, and the use of more or less centralized test facilities. Additionally, much of the statistical data on icing was provided through NACA as well as icing rate meters installed on military reconnaissance aircraft. In any event, it appears that a civil sector effort only to provide aircraft ice protection would have started later and the effort would have been more diffused with more duplication of test facilities, flight tests, investigations and analysis. In view of the above, it is estimated that if ice prevention had been developed solely by the civil sector, the R&D effort would have been at least three times the actual cost.

E-3. Pressure Cabin Development

(1) Early Development

The first really practical work on pressure cabin design was undertaken in the U.S. at McCook Field following attainment of two world altitude records in 1920 and 1921. The first by Major Schroder, reached an altitude of 38,180 feet. The following year, Lt. Macready reached 40,800 feet. In each instance, near disaster resulted because of inefficient oxygen equipment and extreme cold. Such events highlighted the need for providing a pressure compartment for the crew of an airplane. The compartment was to be maintained at a low-level pressure while the aircraft was at higher altitude. Unfortunately, these experiments were made on a small scale, using a heavy metal compartment just big enough to accommodate a pilot and installed in an observation type airplane. This cabin was an elliptical-shaped vessel, 51 inches high by 25 inches wide by 40 inches in length. It was provided with an inward-opening door, resting on a rubber gasket, and several windows for visibility. The supercharged air for this cabin was supplied with a wind-driven blower mounted on the wing. Several flight tests were made at Dayton Ohio, between June and October of 1921, using a U.S. built D-9A and although the pilots had many uncomfortable, dangerous, and possibly amusing experiences and although the project was not then followed up, definitely sound conclusions were drawn from the experiences of the pilots and engineers at the time and recorded as follows:

(a) Automatically operated safety valves and regulating valves should augment hand-operated valves.

(b) Temperature control should be provided.

(c) Ample visibility should be provided.

(d) The experimental supercharged cabin should be large enough to permit steady regulation of cabin conditions, and to provide ample space for two or three assistants to the pilot.

The problem of the pressure cabin was apparently laid aside in 1922 as involving more complications when applied to small military airplanes than warranted.

Some limited efforts were made in Germany and France in the early 1930's. Junkers successfully flew a JU-49 equipped with a detachable two-seater pressure cabin. In France, a Farman aircraft with pressure cabin equipment had some success, but suffered a fatal crash in 1935 that was attributed to the pressure regulating mechanism.

Lack of a pressure cabin went somewhat unnoticed for a number of years until the commercial and military operators were confronted with the desirability - possibly the necessity - of operating aircraft carrying from six to twenty or more people at altitudes above 15,000 feet, without resorting to the use of oxygen. Between 1929 and 1934, power plant development had progressed to the stage where efficient operation of aircraft could be counted on at altitudes between 20,000 and 30,000 feet. Such operation, however, in the case of long range bomber aircraft and commercial passenger carriers, could not be considered if all the oxygen necessary were carried and its use enforced for passengers or military crews. Also, by this time, the large airplane itself had developed a definite type of body and method of construction. The airliners and the military bomber and transport had progressed to a closed, metal body furnished with windows and doors and equipped with means for heating, ventilating, and soundproofing. It was now time to consider a further step in air-conditioning; this was simply the addition of pressure.

In February 1935, a renewed attack was intiated at the Materiel Division of the Air Corps on the problem of creating and maintaining a constant low altitude atmosphere inside an airplane while that airplane ascended to and cruised at an altitude greater than would support human life. A project was initiated to consist of three phases:

(a) The collection and examination of all existing data.

(b) Detailed laboratory and shop work on many aircraft structural and mechanical problems.

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(c) The construction and testing of an airplane embodying a pressure cabin.

The period of research and experiment indicated under Phase 2 extended from the latter part of 1935 to the early part of 1936. The principal research problems were divided into the following main subdivisions and assigned to various units of the Engineering Section of the Materiel Division familiar with the type of work involved; structural, mechanical, airflow and regulation, and physiological. A detailed report on the various phases of the study is contained in Air Corps Technical Report No. 4220 (Ref. 24).

The fundamental problems in the study of pressure-sealed cabins resolved themselves into the questions of sealing joints, obtaining the most advantageous form and size of structure to retain the requisite air pressure without excessive weight, the development of satisfactory valves and safety devices for air control, and the devising of many new details such as doors, windows, and control outlets.

After this fuselage had been satisfactorily sealed and proof-tested, research was continued with individuals occupying the pressure-sealed cabin. No ill effects upon personnel were noted and a number of superstitions surrounding these experiences were dispelled. Experiments were conducted in air flow, rate of flow through various size orifices, and safety valves; and the development of a satisfactory discharge valve (Air Corps drawing X36G507) was completed while experimenting with this fuselage.

Upon nearing the completion of the above experiments under Phase 2 of the program, preparations were made for the undertaking of Phase 3 - the actual construction and operation of an experimental pressure cabin airplane. The basic requirements were set forth in considerable detail by the Wright Field engineers.

(2) Flow of Technology

During June of 1936, the Air Corps contracted with the Lockheed Corporation to build a pressure cabin airplane, designated XC-35, around a Type Specification embodying the basic requirements outlined in Phase 2. The Lockheed Company modified the design of an Electra, incorporating a pressure cabin fuselage of circular cross section to fulfill these requirements. The engines for this airplane were supercharged with exhaust-driven turbosupercharger and the cabin supercharging was accomplished by an auxiliary supercharger mounted on the same shaft as the engine superchargers. The cabin superchargers

had an output sufficient to furnish the cabin under all conditions a volume of air equal to twice the normal amount required. These superchargers were designed on this basis so that in the case of failure of either, an adequate supply of air would be available to maintain the desired cabin pressure and ventilation. The airplane was completed and test flown in May 1937, and delivered to the Materiel Division approximately the first of August for further test and studies. This May flight is considered by historians to be an important aeronautical "first". In 1938, the National Aeronautic Association presented the Collier Trophy "for the year 1937 to the U. S. Army Air Corps for developing, equipping, and flying the XC-35 sub-stratosphere airplane, the first pressure cabin airplane to be extensively flown successfully anywhere in the world." (Ref. 25)

The soundness of the engineering and construction of the XC-35 became apparent immediately upon acceptance. In fact, the ferry flight from California to Ohio was commenced at once and the airplane flew at 20,000 feet for almost the entire distance. By the close of 1938, the airplane had been flown a total of 215 hours, most of which time it was operated at altitudes at which oxygen had previously been required.

(3) Civil Aviation Benefits

The above Army Air Corps project demonstrated that construction of efficient and dependable pressure-cabin aircraft could be accomplished by any of the well-established aircraft manufacturers in the United States. First use of this technology occurred in the Boeing Stratoliner. An improved version, the 307B first flew with pressurized cabin on 31 December 1938. Regular airline service with the Boeing 307B started in April 1940 carrying 33 passengers in its pressurized cabin.

The importance of the pressurized cabin was recognized at the time. This new capability led F. Barrows Colton writing for the National Geographic Magazine in December 1940 (Ref. 26) to describe the Stratoliner as the "airplane of the future." This article acknowledged the earlier Army Air Corps contributions as follows: " . . . in fact Army research in high altitude flying helped pave the way for the stratoliners now operating, a sample of how military and civil flying progress together."

During the 1937-39 period, Douglas and Boeing worked very diligently on the problems of cabin pressurization. Although they duplicated much of the earlier Air Corps work, their efforts in pressure control techniques were a new and important technology addition.

(4) Subsequent Development

During World War II, the newer, particularly experimental aircraft were now incorporating cabin pressurization, each making improvements in the safety and reliability. However, the appearance of large numbers of pressurized aircraft was delayed by the war. In fact, TWA 307's purchased by the military had their pressurization systems removed. In many cases, the unpressurized predecessor aircraft became pressurized in the newer version. The unpressurized DC-4 was the predecessor to the DC-6 which was first used by the military. The first of the famous Lockheed Constellations appeared in 1943 as the military C-69, an outgrowth of the earlier developments in the Electra series. At Boeing, pressurization systems were included in the famous B-29 and the C-97 aircraft. The B-29 was the most important pressurized aircraft of World War II. The first pressurized version (the sixth of the prototype airplanes) flew near Wichita in August 1943.

After World War II, five pressurized aircraft listed below bolstered the post war growth in commercial aviation. Each company drew its technology from engineers that had worked on army experimental aircraft during the war. Each aircraft has its own colorful history and involvement in military R&D.

Lockheed 049 Constellation	1945
Douglas DC-6	1946
Convair 240 Convairliner	1947
Boeing 377 Stratocruiser	1949
Martin 404	1951

These aircraft had many growth features and improvements added to them in the years to follow. They saw primary passenger service well into the jet age.

The advent of the jet-propelled aircraft starts a new chapter in the history of aircraft pressurization. The methods and approaches of the design engineer changed in a most basic manner. The airplane no longer needed the cabin supercharger since this new power plant included a large compressor. First attention to this new design requirement was again to start at Wright Field. A special conference was held at Wright Field in October 1944 exclusively for the purpose of exchanging information and establishing engineering policies regarding cabin pressurization and air-conditioning problems of jet aircraft. In addition to the Army Air Force's Laboratories, the conference was attended by airframe, power plant, and equipment manufacturers. The policies set forth and discussions started at this conference were to pace the industry for many years to come. The higher temperatures associated

with this new air source necessitated more attention to the problems of temperature control and cooling. The combination and integration of this function into the airplane were to become known as the Environmental Control System or ECS. Accordingly, this equipment has carried that designation forward to the present day. At this same time, an important new device emerged to cool the air. This new unit was an expansion turbine developed at AiResearch.

Pressurization became a way of life as the Air Force entered the jet age with the Boeing B-47, KC-135; Lockheed P-80, North American F-86, and Northrop F-89. Higher altitude records were set and obviously, pressure cabins were a necessity for these "stratosphere" aircraft. The Lockheed F-104 "Starfighter" went to 91,249 feet in May 1958.

Meanwhile, in England, the de Havilland Comet entered commercial service in 1952. Successful commercial operation followed until 1954 when tragic air accidents occurred. As a result of the comprehensive investigations that ensued, much technological data was developed on the construction and testing of the pressurized fuselages of turbojet airplanes. Lockheed turboprop Electra entered airline service in 1958 in the U.S. The jet age reached its high point in 1959 with the introduction of Boeing 707, Douglas DC-8, and Convair 880. Several new features were added: separate cabin superchargers driven through an air turbine motor, improved window design, instantly available passenger emergency oxygen systems, adjustable ventilating nozzles, and a variety of fuselage construction approaches. Having reached this high standard of passenger comfort and safety, an era of technological struggle had ended. Many organizations and engineers turned their capabilities toward a new challenge, man's conquest of space.

(5) R&D Costs

The cost of the contract with Lockheed for engineering and construction of the pressurization system in the XC-35 was $155,000. Indirect evidence suggests this was considered to be a large and well-funded contract by engineers of the 1936-38 era. It can be concluded that this contract, coupled with the thousands of engineering hours expended by Wright Field engineers, was a very necessary stimulant and technology foundation for the private expenditures that directly followed. Boeing and Douglas engineers made very important contributions on severely limited budgets. However, without the Army Air Corps efforts, Boeing and Douglas might not have done any work. If this had happened, the B-29 and other aircraft would have been unpressurized. The post war boom in commercial air travel to which the pressurized cabin was an essential contribution might well have been postponed a decade.

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SECTION II-F
AIRCRAFT DEVELOPMENTS

In this section of Air Vehicle Technology, four significant advances are discussed. Three concern aircraft concepts: (1) STOL Airplanes, (2) the Helicopter, (3) VTOL and V/STOL Aircraft. The fourth advance describes Cargo Aircraft development and its associated Cargo Handling System.

The first three of these significant advances deal with air vehicles having special characteristics in the take-off and landing modes. STOL is concerned principally with running take-offs and landings and the attendant low speed flight. VTOL, on the other hand, must consider three modes of operation: vertical flight, transition between vertical and conventional flight, and cruising flight. V/STOL aircraft can operate either as VTOL or as STOL aircraft, depending on loading conditions and, hence, must be designed for two modes of take-off and landing. The helicopter is a special class of V/STOL aircraft which caters principally to efficient hover and low speed flight operations.

The fourth significant advance, Cargo Aircraft, can apply to any of the above types as well as to conventional airplanes. This advance was chosen because of all of the vehicles developed by the military, the cargo airplane most closely approaches the requirements of the civil transport. In addition, an important part of civil aviation is the commercial air freight carrier. As the sizes of these aircraft increase, cargo handling technology becomes highly relevant to the profitability of air freight carriers. Cargo handling technology is, therefore, also treated.

F-1. STOL Airplanes

(1) Early Development

The question of take-off and landing performance requirements, in terms of minimum flying speeds and approach and climb angles, has been a design factor since the earliest days of aviation. Field length requirements (including obstacle clearance) were determined basically through consideration of wing loading and power loading factors based on some fixed wing geometry.

Application of wing geometry changes to improve take-off and landing performance was first given serious consideration in the late 20's and early 30's. Development and application of the split flap (deflecting the bottom surface of the wing trailing edge) to the DC-2 and 3 series aircraft proved advantageous, particularly in

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approach and landing, even though it was principally a drag device and did little to increase the lifting capabilities of the wing. The 1930's also saw the development and application of the simple flap (deflection of part of the trailing edge of the wing) showing that the lifting capabilities of the wing could also be increased and thereby improve both take-off and landing performance.

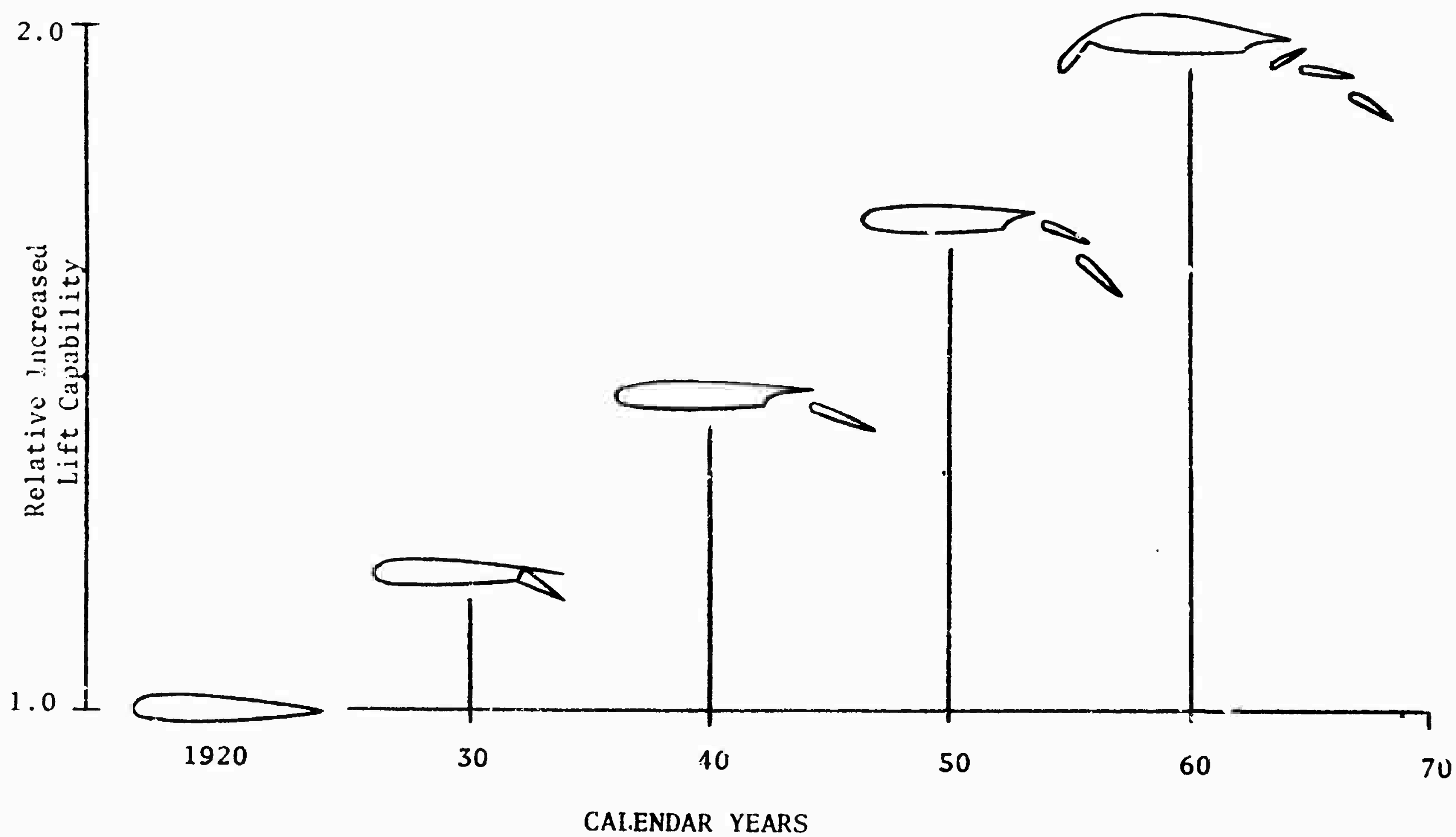
Further improvement in wing-flap systems followed (Figure 6), resulting in such devices as the highly effective single-slotted Fowler flap in the early 1940's. During the 1950's and 1960's, double-slotted and triple-slotted flaps were developed to permit operation of wings at still higher lift values.

Leading edge devices also are helpful in permitting wings to operate at higher angles of attack and higher lift. During the 1920's both Leigh and Handley-Page developed the slotted leading edge. These were incorporated into some production aircraft, principally European. More recently another form of leading edge device was invented; this is the Kruger flap which increases leading edge curvature, when extended. A combination of leading edge devices and trailing edge flaps on one wing leads to the highest lift capability. For this reason, most STOL aircraft use such wing arrangements. The first U.S. examples of such STOL airplanes were the military-developed Stinson 0-49, Bellanca 0-50 and Ryan 0-51's delivered in 1940.

An additional and very effective means for increasing wing lift is to apply engine power to the wing so that it interacts with the normal aerodynamics to increase wing lift capability. The earliest U.S. reduction-to-practice of this concept is found in the 1936 airplane built and flown by Crouch and Bolas. In this machine, the propeller slipstream was oriented to interact with the wing during low speed flight. This is the present day deflected slipstream approach and it becomes most effective when coupled with a wing leading edge and trailing edge flap device. The propeller slipstream concept can be considered to be the forerunner of the present day externally blown flap.

(2) Flow of Technology

Optimum wing loading increases with aircraft size and speed. If take-off and landing speeds and runway lengths are to remain reasonable or even be reduced, it is apparent that the development of higher lift systems is necessary. Devices which depend solely on obtaining lift energy from freestream air flow have reached certain practical limitations. To significantly decrease minimum flying speeds and field length requirements, yet maintain cruise-optimized wing loadings, it is necessary to increase low speed lift capabilities by factors of at least 2 to 3. This additional lift energy must come



2.0
1.0
Relative Increased
Lift Capability
1920
30
40
50
60
70
CALENDAR YEARS

FIGURE 6

from a source other than freestream air. This, then, is a definition of a STOL (Short Take-Off and Landing) aircraft, i.e., an aircraft which derives its total lift energy from both a wing and another source such as a system which converts propulsive energy to lift energy or one which provides supplementary lift via auxiliary power units.

Definition of STOL aircraft is not without its problems, however. Establishment of STOL field length requirements are somewhat elusive. If additional lift energy were applied to the B-52 so that it could utilize a 5000 foot runway or if a C-130 aircraft could be made to use a 1000 foot runway, both could be classified as STOL aircraft even though their runway requirements are significantly different. Therefore, it is considered that the definition of STOL performance requirements is that the minimum safe flying speed be low enough and the non-freestream lift energy be great enough to significantly reduce field length requirements for high wing-loading aircraft as compared to conventional aircraft of the same wing loading.

The primary areas in the development of safe STOL capabilities include lift and propulsion systems capable of producing the energy required for the STOL capability, but the predictability and reliability of the system must be significantly improved before STOL operational capability can be achieved witn an acceptable degree of safety. Another equally important problem area involves the flyability of high wing loading aircraft in the reduced speed environment. Techniques for reliably predicting the behavior (stability and control characteristics and handling qualities) of STOL aircraft appear inadequate at this time. Pilot cue and pilot assist (Control Display) requirements need more definition. Providing low speed moment-producing capability to satisfy safe flying requirements (particularly for multi-engine aircraft) is a severe problem. Lower speeds also magnify the cross wind take-off and landing problem significantly.

(3) <u>Civil Aviation Benefits</u>

Provision of a safe operational STOL capability has a significant payoff in military usability and will satisfy certain commercial transportation requirements. While basic reasons for the military and commercial requirements differ, meeting the requirement of one will, at least, partially and even possibly, completely satisfy the requirements of the other. For instance, high approaches with steep final glide slope capability are necessary for survivability in hostile environments in military use, as well as obstacle clearance requirements. The same type of flight profiles may well satisfy the noise pollution requirements for civil aircraft operating in populated environments. Solution of the military cross wind

landing problem will help solve the commercial landing problem. In addition, the signal outputs from the navigation and guidance systems will probably satisfy both requirements, but the military problem is the more severe due to the forward, austere base considerations. Landing gear design problems for military use will be more severe than for civil requirements due to the unprepared site considerations. Development of landing gears to military requirements should provide the technology for any civil gear requirements (e.g., the air cushion landing gear).

In summary, civil STOL aircraft will benefit markedly from military STOL aircraft developments.

(4) Subsequent Development

Considerable exploratory effort has been undertaken in the last 20 years to provide augmented lift systems as well as development of more sophisticated aerodynamic lift systems by the military. In light wing-loading aircraft, the advanced aerodynamic lift systems were applied to some military aircraft in World War II and later the military used such high lift configurations as the Helio Courier and Fairchild-Hiller Turbo Porter among others. More recently, the military procured and used, on a wide scale in Southeast Asia, the C-7 Caribou which is of the medium wing loading category. At the same time, civil aviation has in the past decade successfully applied advanced aerodynamic lift systems and low speed aerodynamic control augmentation to light wing-loading aircraft resulting in significant improvement in low speed flight and take-off and landing capabilities of that category of aircraft. Examples of the work are the Wren modification of the Cessna 182 and the Robertson modification of a wide spectrum of general aviation aircraft. The military have procured a number of types such as the Cessna O-2A, NARC OV-10 and Helio U-10D and used them in Southeast Asia. This work is mentioned because it has relevance to STOL development not only in the area of aerodynamic lift augmentation but also in the area of low speed aerodynamic control.

In the early 50's the military became involved in the development and application of Boundary Layer Control (BLC) concepts to increase the low speed lift capabilities of aircraft. This was exemplified by the installation of a BLC system in an L-19 aircraft in which speeds down to 25 to 30 mph were demonstrated. This system utilized an auxiliary power unit which pumped high energy air over the flap system, thereby significantly improving the low speed lift capabilities. Although equipment reliability and structural complexity precluded widespread application of this BLC system at the time, it proved, via flight demonstration, that it was possible to achieve significant lift augmentation.

Later in the 50's, the VZ-2 was developed as a V/STOL aircraft. It successfully demonstrated both VTOL and STOL operation and showed that conversion of propulsive energy to lift energy was feasible (in this case through tilting the wing and propellers). It also saw the application of low speed flight control augmentation through provision of a tail fan control system in pitch and yaw and use of propeller thrust control and slipstream energy to improve low speed directional and lateral control. It also used cross-shafting between propellers.

Development and flight test of the XC-142 V/STOL airplane, in the early 60's, further proved the deflected slipstream concept through installation of a sophisticated and programmed flap system for use in transition to increase lift capabilities along with thrust vectoring (through wing tilt). In this system, the entire wing and flap were immersed in the propeller slipstream thereby producing a significant load carrying capacity increase over the VTOL capability even with low forward speeds. Large increases in capability occurred when operated as a STOL type aircraft. This program also advanced the development of technology associated with use of flap type controls in the propeller slipstream to improve low speed control. The aircraft incorporated cross-shafting of the propulsion units thereby eliminating the problem of asymmetric power considerations. Though designed as a V/STOL vehicle, this aircraft advanced the state of the art of STOL development through the deflected slipstream and also defined many of the other problems associated with such areas as: steep gradient approach operation, flight control, aircraft structures, and structural dynamic and operational site requirements.

This same time period saw the development of the French Breguet 941 (McDonnell 188) which was a pure STOL aircraft also using deflected slipstream, cross-shafting, and control augmentation concepts. This aircraft was used by American Airlines and Eastern Airlines in a program to help determine the requirements of a commercial STOL aircraft development.

The early 60's also produced a cooperative program between the USAF and NASA wherein a BLC system was incorporated in a C-130 aircraft. This was probably the first full-scale application of BLC to a high wing-loading aircraft. It allowed a very significant decrease in take-off and approach speeds. In this program, approach speeds down to 63 kts (at least 30 kts below normal C-130 approach speeds) were tested and valuable data obtained particularly in the area of flight control and pilot factors.

Other military developments of the 1960's, though mostly in the area of V/STOL, have added directly to the technology base required for the development of STOL technology. Significant

development, on the part of the military, in the area of propulsion-based lift systems, has contributed much to the existing state of the art. The British development of the Pegasus series vectorable thrust engines was accomplished with the aid of the U.S. military and U.S. military participation in the TriPartite program involving the P-1127 Kestrel aircraft contributed to the definition of problems associated with operational considerations. Subsequent military testing of the Kestrel, particularly by the Air Force at Eglin AFB and Edwards AFB, has contributed to the existing quantitative data base in the areas of aircraft performance, flight control, and near field operating environment. Other U.S. military programs which have investigated propulsion-oriented lift systems, applicable to STOL aircraft, are the XV-4A ejector system, XV-4B lift plus lift cruise engine system, and the XV-5A lift fan system.

(5) R&D Costs

Because much of the technology effort relating to STOL was done as part of the development of conventional and V/STOL aircraft, it is not possible to determine the monies spent in STOL development.

F-2. The Helicopter

(1) Early Development

The helicopter rotor is one of the primary approaches to creating aircraft capable of vertical take-off and landing and of efficient hovering flight. While many attempts were made prior to the 1930's, and a number of machines had produced sufficient lift for vertical flight, none were really successful, primarily because the flight control problem had not been solved.

Even in these early days, the military were interested in the helicopter. For example, in 1922 the Army Air Corps funded the development of the de Bothezat machine.

The successful development of the Autogiro, and its evolution into a wingless "direct-control" rotor aircraft, produced the "breakthrough" needed for the helicopter's successful development. Starting in 1920, the Autogiro's inventor, Juan de la Cierva, undertook its vigorous development. By the late 1930's a successful and useful aircraft had been created and limited production of machines took place, primarily in the U.S. and England. The main U.S. manufacturers of Autogiros were Pitcairn and Kellett. Both the U.S. Army and Navy developed several Autogiros and purchased a small number (Kellett YG-1B and YO-60, 6 aircraft; Pitcairn YO-61, 2 aircraft), but most of the Autogiro research and development work was privately financed. The NACA also contributed to the Autogiro's 384

development by carrying out both model and full-scale testing of a number of aircraft. They also developed analytical methods for predicting aerodynamic and behavior characteristics of lifting rotors; these methods were vital to the design of both Autogiros and helicopters.

With the impetus given by the Autogiro, renewed efforts to develop a successful helicopter took place, and Sikorsky created the first successful one in the U.S. This was also the world's first practical single-rotor, tail-rotor type. Designated the VS-300, this single-place aircraft first flew on September 14, 1939.

On the basis of this machine, Sikorsky proposed the development of a larger, more powerful, two-place helicopter to the Army Air Corps. Funding for its development was provided in 1941. Designated the XR-4, the machine was put into production and between 1941 and 1944, a total of 130 were delivered. These were used in World War II for observation, communication, and rescue work by the Air Corps, Navy and Coast Guard. The modest success of this program led to development and production of increasingly advanced helicopters.

During this period, the early 1940's, several other private organizations undertook helicopter development. Among these were Bell, Hiller, Kaman, and Piasecki. Piasecki Helicopter Company (now the Vertol Division of Boeing) became the second company to obtain a military (Navy) contract for the XHRP-1. This was in 1945. The Piasecki efforts were concerned primarily with the tandem rotor concept, and this continues to be Boeing-Vertol's configuration approach for the helicopter up to the present.

(2) Flow of Technology

While the helicopter has made progress in size, payload capability, and reduction in weight empty fraction (Figure 7), in speed (Figure 8), and in relative range capability (represented by L/D, Figure 9), serious efforts to improve speed and aerodynamic efficiency further have been going on for several years. A number of approaches to such improvement are being made such as:

(a) Compounding of the basic helicopter by adding a separate horizontal thrust device such as a propeller, fan, or jet. Wings may also be added to unload the rotor during high speed flight.

(b) Variable Diameter Rotor, when used in conjunction with compound helicopter features, leading to improved performance and flight smoothness. Bell and Sikorsky are developing such variable diameter rotor systems.

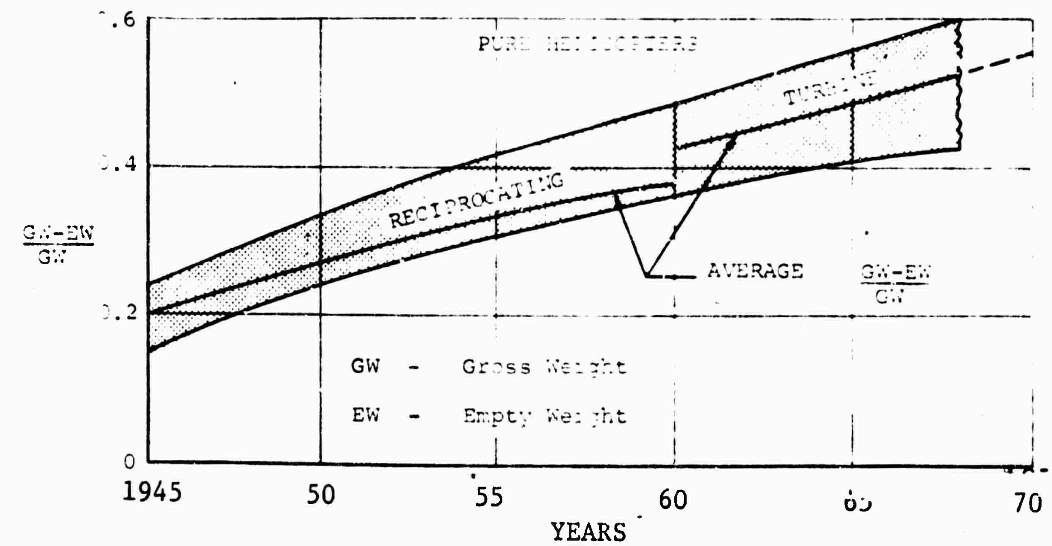


FIGURE 7. PAYLOAD FRACTION

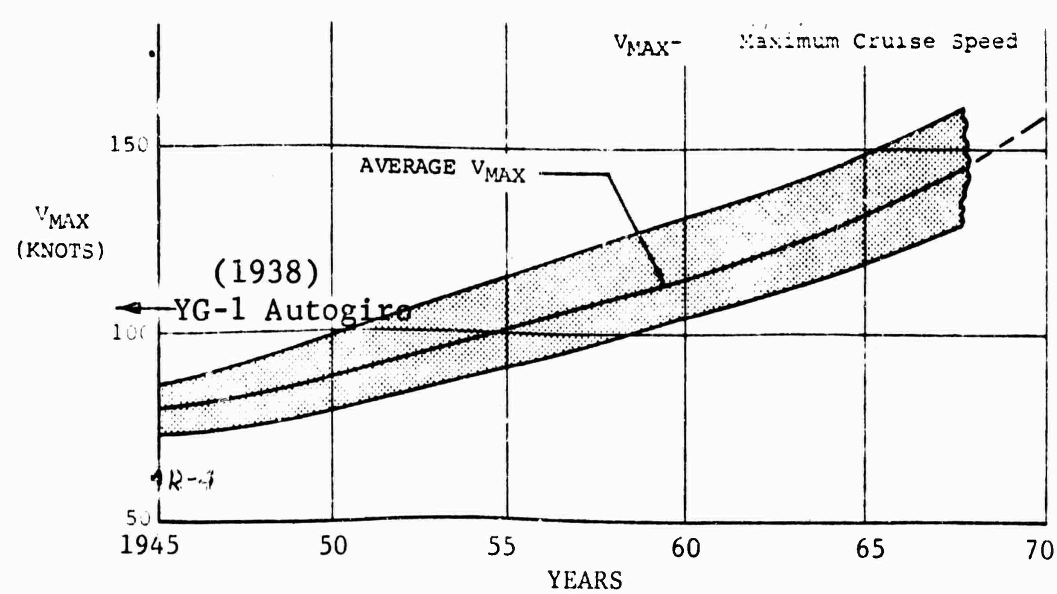


FIGURE 8. MAXIMUM SPEED

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EQUIVALENT LIFT/DRAG RATIO

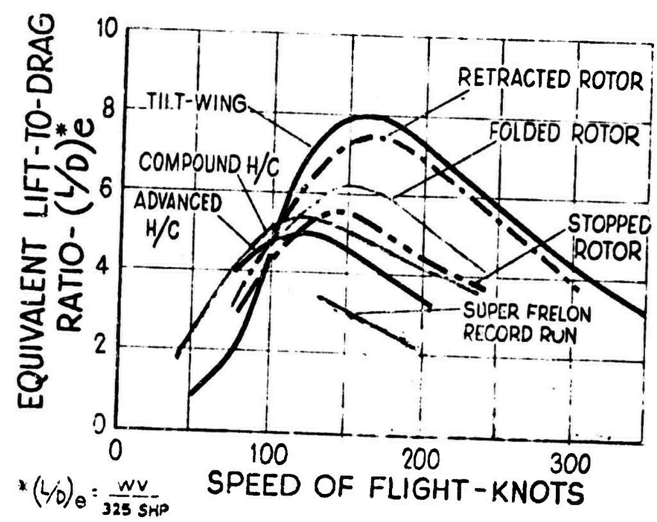

FIGURE 9.

(c) Use of special rotor systems to which more selective blade feathering (e.g., higher harmonic feathering) can be applied to ameliorate or eliminate the classical limitations of retreating blade stall and advancing blade compressibility. Such approaches are represented by Sikorsky's Advancing Blade Concept, Kaman's Controllable Twist Rotor, Fairchild-Hiller's Reverse Velocity Rotor, and Lockheed's Jet Flap Rotor.

The improvements (b) and (c) above are current R&D efforts and are described in Section III-F of this Appendix.

Seven different compound helicopters have been built and flown in the U.S. Four of these were modifications of existing helicopters to permit research into compound helicopter flight characteristics and problems for the Army. These seven machines are:

(a) McDonnell XV-1 - This was the first U.S. compound helicopter and was developed for the Army and Air Force in the 1949-1957 time period. The program was highly successful. Flight speeds of 200 mph were reached.

(b) Piasecki 16H - Developed privately by Piasecki Aircraft starting in 1960, this machine was used in the Army compound helicopter investigation. The machine is equipped with a shrouded propeller which also serves as the anti-torque device.

(c) Bell UH-1 compound - This modification was made for the Army. Two turbojet engines were added for high speed propulsion.

(d) Lockheed XH-51 compound - Modified for the Army program, this machine used a single asymmetrically-mounted turbojet engine for auxiliary propulsion. Speeds of about 300 mph were reached.

(e) Sikorsky S-61F compound - This helicopter was also modified for the Army program. It used two auxiliary jet engines.

(f) Kaman H-2 compound - This was modified for the Navy and also used two jet engines for auxiliary propulsion.

(g) Lockheed AH-56 - This was designed basically as a compound helicopter to meet the Army requirements for a high speed attack helicopter.

The Army and Navy experimental compound efforts took place during the 1965-1968 time period. Each of the machines represented a different rotor concept, e.g., Sikorsky conventional five-bladed

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articulated rotor, Bell two-bladed teetering rotor, Kaman articulated aerodynamic servo-tab controlled rotor, and Lockheed rigid rotor.

The compound is somewhat more complex than the conventional helicopter and more costly to develop and manufacture. For short distance operation and modest cruise speeds (e.g., 150 knots), the compound machine may not be justifiable. For longer distances and higher speeds, compounding has advantages. The range improvement is a function of the lift-drag ratio, a measure of aerodynamic efficiency. Figure 9 compares the French Super Frelon (a 28,000 pound, 37 passenger, helicopter) with an advanced Vertol helicopter and a compound helicopter, in addition to other types of aircraft. It is seen that the compound is decidedly more efficient than the helicopter at speeds of 200 knots and higher. There are other advantages to compounding in terms of reduced vibration, better flight characteristics, and longer component life.

Since the advent of the successful helicopter, many significant technological developments have taken place which were necessary for its advancement. The following are considered to be the key developments:

(a) Understanding of and solution of ground resonance.

(b) Metal-to-metal bonding.

(c) All metal blades.

(d) Composite blades.

(e) Powered controls.

(f) Stability augmentation systems.

(g) Improvement in component life (1000 hrs.)

(h) Use of turbine engines.

(i) Design techniques for rotor load prediction.

(j) Design techniques to minimize vibration.

(k) Anti-vibration devices.

(l) Hingeless rotors.

(m) Elastomeric bearing hubs.

The most common helicopter rotor system uses articulated attachment of the blades to the hub, to reduce blade stresses. One of the resulting blade motions is in the plane of rotation. Since the natural frequency of such motion is close to once per revolution, a "flywheel" type unbalance can occur if the blades move with respect to each other in a certain way. When this motion couples with the airframe motions, e.g., with the landing gear, ground resonance can occur. The energies created are very large and can quickly and seriously damage or upset a helicopter. Such motions are controlled by use of "lag dampers" which control relative motions between blades. First experience with this problem was in 1941 on the XR-2 Autogiro; it was destroyed because of ground resonance. Investigation and analysis by the contractor, the Army Air Corps, and NACA led to good understanding of the problem and establishment of analytical techniques to permit resonance-free operation of helicopters. Such analysis is now part of all helicopter design where applicable. Other ground resonance accidents have occurred such as on the H-5 and H-21 helicopter, but these were due to either improper operation of the helicopter, or to malfunction of components (e.g., the blade lag dampers).

The blades used on the first helicopters followed Autogiro construction practice wherein steel collars were either riveted or spot welded to a steel tube spar. For helicopters, it was quickly discovered that this led to fatigue failure of the spar at the rivet or weld. To eliminate this, an English-developed process called "cycleweld" was used to fasten the collars to the spars. This metal-to-metal bonding technique using thermo-setting plastic adhesives was developed in the 1944-1946 period and used on all production helicopters with this type of blade construction. This was the first production use of metal-to-metal bonding in primary structure in the aircraft industry, and helped provide a solution to the design of all-metal blades that followed.

In 1947-1948, the U.S. Air Force funded the development of an all-metal bonded blade for the H-5 helicopter, with contracts being let to Prewitt and Sikorsky. The first blades used a combination of bonding and riveting. When tests showed the rivets to induce fatigue failures, the all-bonded blade was developed. This blade was used on the Sikorsky H-19 helicopters (1949) and retrofitted to some of the existing H-5 helicopters. The success of these blades and their superior structural and low maintenance characteristics had strong influence on other production helicopters, so that practically all modern machines use bonded metal blades. This first successful use of bonded primary structure paved the way for its acceptance in conventional aircraft.

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An alternative blade construction uses fibrous materials in a compatible matrix material. Representative fibrous or filamentary materials are: glass, boron, carbon (graphite) and Dupont's organic material "PRD-49". Except for glass fibers, all of the others are relatively recent developments. Glass fibers, bonded together with an epoxy matrix, have been available for many years and used in aircraft structures since the late 1940's*. For helicopter blades, important advantages provided by the fibrous materials are: the capability to make blades with optimum twist, taper and airfoil variation; to arrange the material orientation and distribution to produce desired stiffness and mass distributions; and the ability to produce lighter weight blades. Development of such blades was undertaken by the Air Force in 1947 with Cornell Aeronautical Lab. A production helicopter using a hingeless fiberglass shell blade was developed by Boelkow in Germany and is being considered for use by Boeing-Vertol. The fiberglass construction know-how is directly transferable to the other fibrous materials. Increasing use of composite blades can be expected in the future, producing benefits in increased rotor life and improved performance.

The first production helicopters, R-4 and R-5, HRP, and H-13 all used unpowered (unboosted) controls. Pilot-created forces were used to directly cause blade feathering motions. While feedback, friction, inertia, and aerodynamic forces were annoying, they could be handled. Larger helicopters such as the H-19 and H-21 raised required stick force to higher values, and hydraulic power boost was added to the control system, appreciably improving helicopter control force qualities. The first power-boosted systems were researched by the Air Force on an H-5D helicopter in 1947. Hydraulically-boosted controls were used on all H-19 (1949) and on H-21 helicopters. In larger machines, the fully-powered, servo-controlled systems are used, and for safety reasons these are dualized. Most military helicopters developed since the 1950's have used powered controls. Powered controls also are essential to stability augmentation systems used on helicopters.

Characteristically, conventional helicopters are unstable aircraft and significantly more difficult to fly than fixed wing machines. It is possible to reduce or eliminate the inherent instability by incorporating special features in the rotor, e.g., Bell's stabilizing bar, Hiller's "Rotormatic" (aerodynamic servo rotor), and Lockheed's rigid rotor with hub gyros. These systems have adverse features, to varying degrees, in that they may reduce

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*This is described in B-4 of this Appendix, Page 39.

controllability and increase drag; also, they cannot provide all of the stability qualities desired. Use of a stability augmentation system (SAS) based on the conventional autopilot (gyro sensor signal output, servo-control, feedback system) can provide relatively good flying qualities for a helicopter. Of course, the helicopter design must be capable of producing adequate forces and moments for control and trim. The value of stability augmentation systems (SAS) and autopilots was recognized early. First developments were by the Air Force with installation of a Minneapolis-Honeywell E-7 autopilot in a H-5D helicopter and by the Navy using a Sperry autopilot in a HUP helicopter. This was in 1947. All large military helicopters now are equipped with SAS systems. Such systems are essential for all-weather operation. Commercial passenger helicopters will require such systems for safety and to improve passenger comfort and permit all-weather operation.

A substantial portion of the helicopter is made up of continuously-moving elements, such as the rotors (blades, hinges, hub), rotor controls, transmission (main gear box, shafting, tail rotor gear box), and engine(s). These dynamic components experience continuously-cycling loads and vibratory excitations. The problem of component life is much more severe than for conventional aircraft and, not unexpectedly, the early helicopters had rather low dynamic component life; for example, the H-5 helicopter rotors required overhaul and replacement of rotor components at 200 hours but bearings failed in 5 to 6 hours. The requirement to meet 1000 hours between overhauls was levied on the H-19 development program by the Army and Air Force in 1949. This requirement proved to be difficult to meet, but the pressure by the military for such capability has led to improved helicopter design for fatigue and wear minimization, and extensive testing in the laboratory and in flight. An important development was statistical fatigue damage and life prediction methods, started in 1949. Present day helicopters are immeasurably better than the 1940-1950 machines and are continuing to improve, but the problem of rotary-wing maintenance is still a major question for commercial operators. Design techniques and improved structural material will produce long lived helicopters. Two thousand hours component life is realizable now for many major components while others have even higher life (some hubs are achieving 6000-7000 hours life). Further than this, maintenance manhours per flight hour also has been improving. This ratio for the 14,000 pound H-21 was 10 hour/flight hour, while for the more recent 19,000 pound CH-46 it is about 5 hour/flight hour. An important development has been the Sikorsky Blade Inspection Method which visually indicates when a blade has developed a fatigue crack. Now, such blades are operated until a crack develops. Retirement based solely on flight hours is no longer used.

Introduction of the turbine engine into the helicopter has had a profound effect on its development. It has permitted the building of helicopters with much improved empty weight/gross weight fraction, larger size, higher range and speed, longer life, and lower maintenance. Use of the turbine in production helicopters started about 1956 (Bell UH-1 and Kaman HTK), but Sikorsky and Piasecki also had prototype helicopters flying with turbines installed (XH-39 and YH-16A) in 1956.

As can be expected, the rotor sees a very complex, load-producing environment. From the beginning of helicopter development, efforts to improve methods of rotor load prediction have been going on. Air Force funding of such efforts started in 1948 with Princeton University. The introduction of the computer and extensive instrumented flight testing has led to a much better understanding of the complex, interrelated aeroelastic and aerodynamic forces seen by the rotor. The important areas of viscous and unsteady aerodynamics have been applied to the rotor-load effort. Predictive capability is considered fair at present. Only the large companies, however, e.g., Sikorsky, Bell, Boeing-Vertol, have the capability of adequately handling the rotor loads prediction problem.

Vibration has been a major problem in helicopter development*. The problem appears in the areas of fatigue loads, structural resonance, early failure of components, and in pilot and passenger discomfort. The latter area becomes more difficult as helicopter size increases. Number of blades and rotor arrangement (tandem, single rotor) affect the vibratory conditions. As in the case of rotor load prediction, strong efforts have been mounted by the major companies to determine rotor vibratory forces, methods of isolating these, and design analysis methods to eliminate airframe resonances. The techniques used for rotor load prediction have been expanded to predict the vibratory inputs, forces, and motions. A key area is the prediction of the unsteady aerodynamic pressures. Methods for reducing the rotor forces revolve around the use of passive isolation systems (Bell H-13) and active isolation systems (e.g., the Kaman dynamic anti-vibration isolation system and the Sikorsky Bifilar absorber which is used on the S-61). Both the Army and Air Force initiated work on vibration absorbers and isolators in 1945.

While rigid or hingeless rotors were the vogue during the early attempts to build helicopters, they were abandoned in favor of

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*See D-2 of this Appendix, Page 66.

the articulated blade rotor. Most of the production helicopters have used variations of the articulated rotor. Several attempts during the 40's and 50's were made to build helicopters using rigid rotors. Small amounts of Army funding were put on the XR-11 (tandem rotor) and Landgraf H-2 (lateral twin) during the mid 1940's. The first successful development of the hingeless rotor was privately developed by Lockheed as the XH-51 helicopter. Some were bought for research by the Navy, Army, and NASA. Also, a modification was made for the Army's compound helicopter test program. In Germany, starting about 1965, Boelkow developed a "soft", hingeless rotor using fiberglass construction, the Bo 105. Boeing-Vertol has license rights to the machine and is interested in this rotor system for possible use on tilt rotor type V/STOL aircraft. Sikorsky has done an extensive development effort on an extremely rigid, coaxial configuration rotor in furtherance of the Advancing Blade Concept (ABC). The key problem was development of a twisted, tapered blade using a 17-foot long, single-piece titanium spar. The completed blade contains foam plastic and a fiberglass shell. The ABC concept was developed by Sikorsky with the Government providing wind tunnel facilities and supporting the full scale tests of the Sikorsky rotor system.

A problem which has plagued all helicopter programs is the size and complexity of rotor hubs, particularly for the articulated rotor systems. The size of the hub, and its resulting frontal area, can greatly increase overall drag. The complexity of rotor hubs directly influences hub component fatigue life, needed hub overhaul schedules, and maintenance. A recent development in materials science (within the last 5 years) has produced a reliable method for bonding thin layers of resilient elastomeric (rubber) to alternate layers of metal structure. This development was pioneered by the Lord Manufacturing Company, who has begun rotor hub programs with Boeing/Vertol and Bell Helicopter. These "elastomeric" hubs achieve rotor torsional, flapping and lagging motions in one unit without bulky, conventional mechanical hinge assemblies and greatly reduce rotor hub drag and complexity. They are being used successfully on the Enstrom helicopter rotor. R&D effort to develop elastomeric bearing rotor hubs has been funded principally by the Army.

(3) Civil Aviation Benefits

Despite the development and substantial use of large military machines and the large quantities produced (Figure 10), the helicopter has seen very limited use in commercial air transport to date.

Various studies have verified the pressing need for rapid, point-to-point short-haul transport. Numerous methods for doing this are being studied, such as V/STOL and STOL aircraft and high

HELICOPTER PRODUCTION

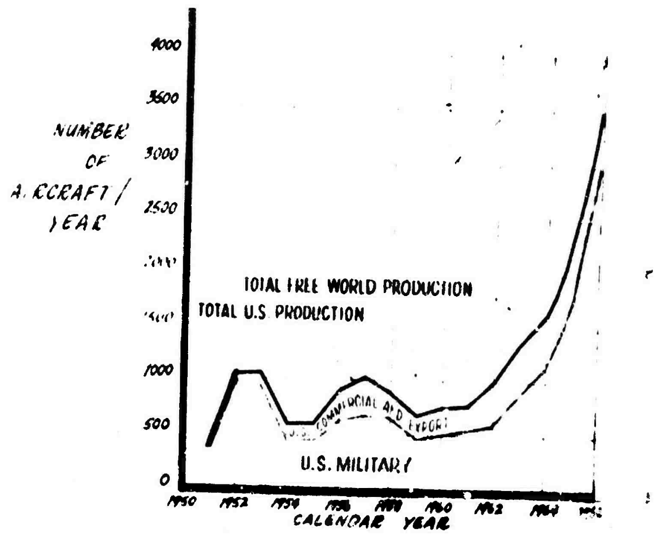

FIGURE 10.

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speed ground transportation. The two major U.S. helicopter companies, Boeing-Vertol and Sikorsky, have designed large commercial transport helicopters which they believe could produce profitable short-haul operations. But without firm customer support or government sponsorship, they probably will not undertake the costly development required. Probably a mixture of transportation systems will provide the best solution. Because the cost of developing such systems and the risks involved, and because of governmental concerns and controls, totally private development of these systems may not be possible.

While the commercial transport picture is bleak, the other civil uses of the helicopter are being strongly exercised:

Executive transport and air taxi.

Support of petroleum production (personnel and materiel transport, rig erection, exploration for oil sources).

Construction (aerial crane).

Logging operations.

Agriculture and forestry (crop dusting, fertilization, etc.).

Forest fire fighting.

Cattle control.

Industrial patrol and inspection (power lines, pipe lines).

Police activities (crime prevention, traffic control).

Emergency service (rescue, highway accident assistance, ambulance, emergency aid).

Municipal fire fighting.

(4) Subsequent Development

In its varied uses the helicopter has found good acceptance, and its use in these various activities is expanding. Many of the civil helicopters in production for these uses are derivatives of the military machines or have been helped into production by military procurement, after being privately developed.

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It should be noted that direct conversion of a military helicopter design to a civil vehicle may not provide the best machine for a specific civil activity. The expanding market for specialized rotorcraft, e.g., police helicopters, can be expected to cause the manufacturers to produce machines more optimally designed for these uses. The developments in technology, hardware, and operational techniques fathered by the military are of great value in these civil developments and activities (e.g., helicopter medical evacuation in Vietnam and crane activities).

(5) R&D Costs

Over 30,000 helicopters have been built in the U.S. through 1971 (See Figure 10 and Table II). It is guessed that these represent perhaps 10 billion dollars worth of production. It was not possible to obtain a good estimate of the R&D cost involved because much of this was buried in the production programs. If it is assumed that from 3 to 5 percent of the production cost involved R&D, the R&D costs would be between 300 million dollars and 500 million dollars. These costs were principally borne by the Military Services.

F-3. VTOL and V/STOL Aircraft

(1) Early Development

Attempts to develop a successful form of VTOL aircraft antedated the Wright Brothers' activity and involved numerous concepts. Of these, only three concepts had a reasonable basis for success: the ornithopter, cyclogiro, and lifting propeller. It is interesting to note that in nature, only the ornithopter approach has achieved VTOL-capable flight, such as the hummingbird. Larger birds also are ornithopters but are incapable of hovering, indicating a size effect limitation. Up to the present, man-carrying ornithopter type VTOL aircraft have been beyond our technological capability.

A close approximation to the ornithopter exists in the cyclogiro which employs rotary wings instead of oscillating ones. Serious efforts to develop cyclogiros took place during the 1930's in the U.S. and Europe. NASA performed tests on a cyclogiro system conceived by Havilland H. Platt; but the aerodynamic efficiency proved to be low. Subsequently, new cyclic feathering motion programs for the blades were devised and explored. Tests by Prof. K.F. Kirsten at the University of Washington during the late 1930's indicated good efficiency for such a system. However, problems in system mechanization, structure, and vibration posed inordinate

TABLE II

MAJOR AUTOGIRO & HELICOPTER DEVELOPMENTS - USA

AIRCRAFT	TIME PERIOD	TOTAL NO. BUILT	REMARKS
AUTOGIROS:			
Cierva Nr 4 (Spain)	1923	1	First successful Autogiro, used articulated blades
Kellett (YO-60)	1941-43	7	For Army Air Corps, YO-60 redesign of YG-1B
Pitcairn XO-61, YO-61	1941-43	6	For Army Air Corps
HELICOPTERS:			
Bell (Mod 47), H-13 Series	1946-Present	4,460	To 1971. Private develop. & FAA certified, 2,445 Civil Helicopters
Bell XR & YR-12	1946-	13	Had numerous problems. Contract cancelled.
Bell (204), UH-1 Series	1955-Present	10,027	Used extensively in Vietnam. 231 Civil produced.
Bell (200), OH-58	1968-Present	1,965	Successor to OH-6, 733 Civil produced.
Cessna (CH-1), YH-41A	1953-62	20	Cessna discontinued helicopter activities in 1962.
Firestone (GA-45) XR-9A&B	1944-46	2	Firestone was successor to Pitcairn Autogiro Company
Fairchild Hiller (UH-12) H-23 Series	1949-1962	1,100+	Hiller merged with Fairchild. Estimate over 1,100 built.
Fairchild Hiller, FH-1100	1961-Present	200+	Started as Army OH-5A. 5 only bought, redesigned as Civil FH-1100.
Gyrodyne QH-50	1959-	400+	Drone for Navy DASH program.
Hughes XH-17	1945-1952	1	55,000 lb GW test bed for tip driven heavy lift helicopter
Hughes (300) TH-55	1956-Present	1,524	Developed privately. 921 for Civil use.
Hughes (500) OH-6	1961-Present	1,749	296 for Civil use.
Kamar (K-240) HTK-1 Series	1951-53	29	For Navy

AIRCRAFT	TIME PERIOD	TOTAL NO. BUILT	REMARKS
HELICOPTERS: (Cont'd)			
Kaman (K-600) HUK, HOK, H43 Series	1951-68	344	For Navy, Marines, AF
Kaman H-2 Series	1959-65	190	For Navy
Kellett XR-8 & 8A	1943-45	2	AF-Army. Intermeshing rotors (Snychropter) Interference between blades.
Kellett XR-10	1945-48	2	AF-Army. Intermeshing rotors (Snychropter) Interference between blades.
Lockheed (280) XH-51A	1961-68	5	"Rigid" (hingeless) rotor helicopter. 2 for Army and Navy, 1 for NASA.
Lockheed (286) AH-56	1966-Present	10	Attack helicopter for Army. Originally planned for production, but only RDT&E approved.
Platt Le Page XR-1 & 1A	1940-41	2	Twin lateral rotors for Army Air Corps. Not fully successful.
Sikorsky VS-300	1939	1	First successful US Helicopter. Private development.
Sikorsky (VS-316),R-4 Series	1941-44	131*	First US production helicopter, military use.
Sikorsky (S-51), R-5 Series	1943-46	437*	Used in Korea, some civil acft built.
Sikorsky (V-316A), R-6 Series	1943-45	229	Advanced design replacement for R-4.
Sikorsky (S-52), H-18	1947	95	For military.
Sikorsky (S-55), H-19 Series	1949-61	1,271*	For military, some commercial use.
Sikorsky (S-56), H-37 Series	1951-62	156	For Army, Largest (31,000 lbs) US production helicopter at the time.
Sikorsky (S-58), H-34 Series	1952-69	1,775*	For military. Sikorsky privately modifying 70 to twin turbine power.
Sikorsky (S-59), H-39	1949	2	For military, turbine powered helicopter.
Sikorsky (S-61), H-3 Series	1957-Present	530*	Civil and military use.
Sikorsky (S-62) HU25-1G	1958-Present	79*	For Coast Guard and Civil use.

AIRCRAFT	TIME PERIOD	TOTAL NO. BUILT	REMARKS
HELICOPTERS: (Cont'd)			
Sikorsky (S-64) CH-54A	1963-Present	97*	Aerial crane. Privately developed. Military and Civil use.
Sikorsky (S-65) CH-53A	1963-Present	481*	Marine helicopter, same dynamic components CH-54A.
Vertol (Piasecki) HRP-1	1945-48	23	Boeing-Vertol successor to Piasecki. Navy development.
Vertol HRP-2	1948-50	5	Navy program.
Vertol (Piasecki PV15) H-16 Series	1946-56	2	Army-AF. Largest helicopter built to that time. 32,000 lbs GW.
Vertol (Piasecki PD-18) H-25 Series	1946-54	344	For Army and Navy
Vertol (Piasecki PH-42) H-21 Series	1949-60	739	Developed for Air Force Arctic Rescue, certified and produced for Civil use, 8 built
Vertol (107) CH-46	1956-71	642	For Army and Marines. 7 in Civil use.
Vertol (114) CH-47	1959-Present	678	For Army.

*Includes Production for US and Foreign.

difficulties. The helicopter's success had a chilling effect on development of such concepts as the cyclogiro, and no further serious work has been done in this area.

The most serious VTOL efforts were based on the use of the propeller. In general, large propellers were employed to obtain sufficiently reduced disc loading so that adequate vertical lift could be obtained for the modest powers available. The distinction between helicopter and V/STOL is blurred here. The early experimenters did not differentiate between low and high disc loading concepts; this distinction is a more recent development. Further, no thought was then given to the significance of V/STOL as opposed to pure VTOL.

While some of the propeller-equipped aircraft were able to rise vertically, the control systems were inadequate, and successful flight was not possible. (This same problem existed for the early helicopter). During the 1909-1923 period, Emile and Henri Berliner engaged in the most aggressive efforts to develop a propeller-type VTOL machine. Vertical take-off and brief hovering were achieved. Other early experimenters and inventors anticipated some present-day concepts, for example:

Descazes (France) built, but did not fly, an airplane with coaxial horizontal propellers mounted above and in between the wings.

Leinweber-Curtiss (U.S.A.) built a twin-lateral lifting propeller machine.

Hall (U.S.A.) proposed a fan-in-wing design.

A Hamilton airplane was modified by J.C. Johnson to have large two-bladed, horizontally rotating propellers below the wings, primarily for STOL. These propellers could be stopped for cruise flight.

Breguet proposed and patented the fan-in-wing concept.

General Electric funded design and construction of a lifting single prop-rotor machine during the mid-1940's.

Havilland Platt proposed a twin lateral tilt prop-rotor machine to the U.S. Air Force during the late 1940's.

(2) Flow of Technology

Despite these numerous activities, no VTOL or V/STOL machine flew successfully prior to the helicopter's successful development. After this success, and with the availability of the turbine's high power and light weight, there was a very rapid bourgeoning of flyable VTOL and V/STOL aircraft, based on a variety of propulsion system approaches. Table III summarizes the most important of these.

Serious government VTOL R&D began in 1950 with the Navy and Air Force funded "tail-sitters". The XFY-1 (Convair) and XFV-1 (Lockheed) were propeller-driven VTOL aircraft prototypes. They were designed to accomplish vertical take-offs and landings. The XFY-1 was the only one able to achieve VTOL, the XFV-1 flew conventionally with special landing gear, never demonstrating VTOL. The Air Force X-13 (Ryan) was a jet-powered VTOL, grouped with the tail-sitters, but more rightly called a "chin-hanger", since it was designed to hang on a hook from a suspended cable. The X-13 was a successful technology demonstrator, achieving in 1954 VTOL and Mach = 0.8 cruise. No tail-sitter program has been funded since 1957.

VTOL research continued with the Army's interest in battlefield mobility, and the funding of three programs for aerial jeeps in 1957. None of these programs was successful in terms of practicality, but the method of using ducted fans for VTOL was demonstrated.

The last strictly VTOL program was the Army-funded XV-4A (Lockheed). This aircraft was designed to demonstrate VTOL capability using the jet augmenter thrust concept. It was only marginally successful because the lift augmentation achieved was less than predicted. The aircraft was later modified to become the XV-4B, in which the augmenter system was replaced with lifting jet engines.

V/STOL R&D began in 1951 with the Air Force and Army-funded XV-3 (Bell Helicopter) tilting rotor aircraft. The Transcendental Models 1 and 2 were also built and flown. The XV-3 aircraft was highly successful in demonstrating an efficient hover capability, overload running take-off, and smooth transition of the tilt rotor. Work in this area has continued up to the present in the form of numerous design studies. The most recent and important variation of the tilt rotor is the stoppable, stowable rotor. Recently, the Air Force has funded design studies and model tests for three different stowed rotor concepts (Bell, Sikorsky, Vertol) and the state-of-the-art is considered far enough advanced to build a prototype.

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TABLE III

US VTOL & V/STOL PROGRAMS (R&D)

MODEL NO		COMPANY	CONTRACT AWARDED PROJ-START	FIRST FLT	CONTR TERM.	TOTAL GOV'T FUNDS	BRANCH	REMARKS
TAIL SITTERS (VTO) (VTOL)								
XFY-1	Pogostick	Convair	1950	1953	1954	20.0 M	Navy	Successful
XFV-1	Pogostick	Lockheed	1950	1954	1955	20.0	Navy	Limited Success
X-13	Vertijet	Ryan	1950	1956	1957	12.3	AF	Very Successful
AERIAL JEEPS (VTOL)								
VZ-6		Chrysler	1957	-	1960	.661M*	Army	Unsuccessful
VZ-7		Aerophysics	1957	1958	1960	.387M*	Army	Achieved Goals
VZ-8		Piasecki	1957	1960	1960	.653M*	Army	Achieved Goals
						*Denotes Total As of June 1958		
JET EJECTOR (VTOL)								
XV-4A	Hummingbird	Lockheed	1961	1962	1962	3.50	Army	Marginal Vertical Lift
TILTING ROTORS								
XV-3		Bell Helicopter	1951	1955	1958	9.80	AF Army	Very Successful
Model 2		Transcendental	1952	1955	1957	0.34	Army	Contract Overrun, Terminated
K-25		Kellett	1956	-	1956	0.06	Army	Design Study Only
DEFLECTED SLIPSTREAM								
	Aerodyne	Collins	1952	1957	1960	1.30	Navy Army	Wind Tunnel Test Only
	(Study)	Fairchild	1956	-	1957	1.00	Army	Tethered Model Design Study
VZ-5FA		Fairchild	1956	1957	-	4.50	Army	Tethered Hovering
VZ-3RY		Ryan	1956	1958	-	2.50	Navy Army	(1.0M Spent in FY 56)
	Convoplane	Goodyear	1956	-	1958	0.07	Army	Design Study

MODEL NO		COMPANY	CONTRACT AWARDED PROJ-START	FIRST FLT	CONTR TERM.	TOTAL GOV'T FUNDS	BRANCH	REMARKS
DEFLECTED SLIPSTREAM (Cont'd)								
PA-2C		Piasecki	1956	-	1957	0.85M	Navy	Design Study
	(Study)	Beech	1957	-	1957	0.05	Army	Design Study
ADAM I II	(Study)	LTV	-	-	-		AF	Design Study
VECTORED JETS								
X-14		Bell Aerosp	1952	1954	1962	2.2	AF	Very Successful, Still Flying
ATV	Air Test Veh	Bell Aerosp	1954	1954	1956	0	AF	J-69 Engines Bailed by AF to Bell
XF-109		Bell Aerosp	1957	-	1959	-	Navy AF	Design Study
P1127	Kestrel	Hawker-Siddeley	1958	1960	1971	20.0	Tri-Service	Tri-Service Test Program
AV8A	Harrier	Hawker-Siddeley	1965	1966	-	(See Note)		BS53 (Pegasus) Engines Partially Funded by US
LIFTING FANS								
System 606A		AVRO (Canada)	1955	-	1960	2.1	AF	Wind Tunnel and Design Study
VZ-9	AVROCAR	AVRO	1958	1959	-	6.3	Army AF	Flew in Ground Effect Only, Vertical Lift Defct
2-C	Omniplane	Vanguard	-	-	1962	0.25	AF	Never Flown
XV-5A		GE/Ryan	1961	1964	1966	20.0	Army	Very Successful, Aircraft Damaged
XV-5B		GE/Ryan	1966	1966			NASA	5A Rebuilt, Flying

MODEL NO	COMPANY	CONTRACT AWARDED PROJ-START	FIRST FLT	CONTR TERM.	TOTAL GOV'T FUNDS	BRANCH	REMARKS
TILTING PROPELLERS, DUCTS							
VZ-4DA	Doak	1956	1958	1960	3.5	Army	0.4M Spent in FY 56
X-100	Curtiss-Wright	1958	1960	1960	0		Company Funded
X-19	Curtiss-Wright	1962	1964	1964	12.0	Tri-Service	Aircraft Lost
X-22A	Bell Aerosys	1962	1966	Now	25.0	Tri-Service	Successful, Still in Use
TILT WING							
VZ-2PH	Vertol	1956	1957	-	2.0	Navy Army	Successful
X-18	Hiller	1956	1959	1960	6.0	AF	Project Cancelled, Overrun
K16B	Kaman	1956	-	1962	2.5	Navy	Never Flown
XC-142A	LTV	1962	1964	1970	147.4	Tri-Service	Operation Suitability Tests, Very Successful
CX-84	CANADAIR (Canadian)	1963	1965	-		AF	Small Amount US $ Spent on Test Prog
LIFTING JETS, VECTORED CRUISE							
XV-4B Hummingbird	Lockheed	1967	1968	1970	6.3	AF	Aircraft Crashed
D-188A	Bell	1958	-	1959	10.9	Navy AF	Design Study
US/FRG V/STOL Tactical Fighter		1963	-	1967	7.0	AF	US/FRG (Germany) Design Study

MODEL NO		COMPANY	CONTRACT AWARDED PROJ-START	FIRST FLT	CONTR TERM.	TOTAL GOV'T FUNDS	BRANCH	REMARKS
WING ROTOR								
	Vertiwing	Ryan				None		In-House Design Study
	Rotor Wing	Hughes	1966	-	1970	0.58	Navy/ Army	Design Study
STOWED ROTOR								
XV-2	S-57(XV-2)	Sikorsky		-			AF	Design Study
	Studies	Lockheed		-			Army	Design Study
	Studies	Bell Helicopter						
	Studies	Sikorsky	1969	-	1972	2.5	AF	Design Studies, Wind Tunnel Tests
	Studies	Boeing-Vertol						

In 1952, work also began on the deflected slipstream V/STOL concept, which makes use of large multi-element slotted flaps to deflect propeller or fan thrust 90° to achieve vertical lift. The Collins Aerodyne, Fairchild VZ-5A, and Ryan VZ-3RY were all built and tested during the 1950's, demonstrating the feasibility of this concept. All of these aircraft used propeller thrust, but had only marginal performance. Since then a good number of studies have been done on the deflected slipstream propulsion concept, the latest being the Ling-Temco-Vought ADAM I and II (Air Deflection and Modulation).

The vectored jet V/STOL concept arose in 1952 with the Air Force-funded X-14 (Bell Aerospace) test vehicle. Bell also demonstrated another vectored jet V/STOL aircraft in the company-funded Air Test Vehicle (ATV). The J-69 engines were loaned by the Government. These two early vehicles proved the feasibility of jet vectoring for vertical lift. This technology carried over into the British P1127 effort, the prototype Harrier, and Kestrel V/STOL fighter. These foreign efforts have evolved into the world's only operational V/STOL vehicle, the AV8A Harrier. It presently has no civil application, but answers military needs for mobility and dispersion at forward areas. The U.S. involvement in this was in the partial funding of the Harrier's Bristol-Siddeley BS-53 (Pegasus) engine.

The lifting fan (or ducted fan) V/STOL concept began in the late 1950's with Air Force funded studies of the concept. The Ryan XV-5A lift-fan V/STOL in 1961 was funded by the Army. The XV-5A program was very successful insofar as demonstrating the use of remote, tip-driven lift-fans from a central power plant. The XV-5A after a flight accident has been repaired, modified and designated the XV-5B and is now being used in a joint Army-NASA test program. Another related effort of the late 1950's is grouped with the lift fans, although it also had the characteristics of the lifting jet and jet augmenter concepts. The Avrocar (AVRO Co., Canada) was funded by the Air Force, Army, and Canadian Government. It subsequently failed to prove V/STOL capability.

One of the most successful V/STOL concepts was started in 1956 with the Army-funded VZ-4D (Doak) tilting-duct aircraft. This propulsion concept grew into the Tri-Service X-22A (Bell Aerosystems) program in the 1960's. This aircraft is still flying as a flight control test bed, variable-stability system aircraft. A version of this concept replaced the tilting ducts with propellers; Curtiss-Wright built the open-propeller X-100 in the 1958-1960 with its own funds, to demonstrate the effectiveness of propeller radial force as an aid to conversion. A Tri-Service program was subsequently undertaken in 1962 to test the X-19 tilt-prop V/STOL. This aircraft had only marginal success due to many development problems.

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The most successful, and most heavily funded V/STOL concept is the tilt wing. Work began in 1956 with the Army and Navy-funded VZ-2PH (Vertol) and the Air Force-funded X-18 (Hiller). The VZ-2PH verified the principle of the tilt-wing and its superior overload STOL capability. The Tri-Service XC-142A (Ling-Temco-Vought) program began in 1962; five aircraft were built and flown, and operational suitability testing was done and included demonstrations on aircraft carriers and unprepared landing fields. The operational feasibility of tilt-wing was proved. But the tilt-wing program, of which the XC-142A was a part, was terminated in 1970. The Air Force has continued a program of V/STOL propeller development from the XC-142A technology. The use of titanium spar blades and foam-filled or bonded honeycomb fiberglass blades to save weight was proven; and propeller static thrust prediction techniques were improved. Also, the Army is continuing a V/STOL propeller technology program that is considering adaptation of new materials as well as new design concepts. The advanced state-of-the-art of V/STOL propeller technology is totally due to the government tilt-wing program.

Lifting jet V/STOL concepts are attractive because of their inherent high cruise speed capability; work began in 1958 with the Air Force-funded D-188A (Bell Aerosystems) design study. In 1962, the XV-4A jet was modified to replace the augmenter system with vertically-mounted direct-lift jets plus a vectoring system for the cruise engine. This aircraft flew successfully. Another version of the jet-lift cruise engine with vectorable thrust was the US-FRG V/STOL Tactical Fighter studied during 1963-1967. This aircraft was not built.

Preliminary efforts in wing-rotors using such concepts as delta planforms, have been considered for VTOL; however, efforts have primarily been limited to analytical and model programs. This work has been done by Ryan and Hughes Tool Corporation with the Navy funding the latter's work.

The development of these V/STOL vehicles over the past twenty years has served to establish a broad state of the art usable for many possible V/STOL designs.

(3) Civil Aviation Benefits

Since fifty percent of all domestic trunk airlines passengers travel less than 500 miles and since central airports and conventional transports appear not to be efficient solutions to the short-haul need, V/STOL vehicles could supply a needed element in the multi-system transportation arena. Civil aviation has maintained keen interest in military V/STOL developments for an answer to this short-haul transportation problem.

Other civil aviation fields could benefit strongly from V/STOL vehicle development. Rotary wing V/STOL vehicles with high

cruise speed (e.g., tilt rotor) could find immediate uses in executive transports, air taxi service, police and crime prevention, rescue and ambulance service, and industrial special purpose patrol and inspection. Larger vehicles with large payload and long hover time can be used for rescue and other emergency actions, agriculture and forestry work, fire fighting, commercial and industrial construction.

(4) Subsequent Development

Germany, until just recently, was developing a tandem tilt-wing transport, the VFW VC-400; the propellers and gearboxes for this program were developed by Hamilton-Standard. This aircraft represented the only civil aviation V/STOL transport hardware program. The VC-400 was being funded under a German Government program to find a workable aircraft to expand and supplement the conventional short-haul market. This program was conceived at a time when tilt-wing and propeller technologies were adequate to permit a successful V/STOL transport development. The fact that the program was terminated in the midst of its hardware development testifies to the existing indecision regarding the economic merits of V/STOL. As a consequence, there now exists no program or plan to develop a V/STOL tilt-wing transport, or any other concept, for either military or civil needs.

(5) R&D Costs

Government funding is shown on Table I. In some cases, only the known partial funding is shown. It appears that about 362 million dollars have been spent on VTOL and V/STOL R&D. The costs estimated for each service are. Army, 53 million dollars; Navy, 48 million dollars, Air Force, 47 million dollars, Tri-Service, 214 million dollars.

F-4. Cargo Aircraft - Cargo Handling

(1) Early Development

Early transport aircraft were built and developed primarily by industry to transport people and government mail. One of the first of these aircraft was the Boeing Model 40 built in 1925 for the United States Post Office Department. This airplane was capable of carrying two passengers and 500 pounds payload.

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However, the vehicle was primarily dedicated to mail hauling. A modification of this aircraft resulted in the "Monomail" Model 80 which carried 12 passengers and 500 pounds for baggage and mail.

The Air Corps entered this field of development in 1925 with the Douglas C-1, a 6483 pound airplane powered by a Liberty V-1650-1 engine. The airplane had a payload capability of 500 pounds. It was a versatile airplane designed for carrying cargo, transporting troops, or if needed, for air evacuation. It had a maximum speed of 121 miles per hour and a service ceiling of 16,000 feet.

The next significant development was the C-20 built by General Aviation (an affiliate of General Motors) in 1931. This was an aircraft of 22,500 pound gross weight powered by four Pratt & Whitney R-1860 engines. This aircraft had a wing span of 99 feet. It was one of the first large military transports being capable of carrying 32 passengers or 5500 pounds of cargo.

In 1936, the C-32 was built by Douglas at a gross weight of 18,200 pounds and a capacity for 3,506 pounds of payload. This was a conversion of the Douglas civilian DC-2 design to a military aircraft. This aircraft, powered by two Wright Aeronautical R-1920-25 engines, finally led in 1941, to the famous version known as the C-47, the military counterpart of the more famous civilian DC-3 transport. However, before the C-47 was developed there were fore-runners - the C-38 in 1937, the C-39 in 1938 and the C-41. The C-38 and C-39 were of the same size and capacity as the C-32, while the C-41 had a gross weight of 25,000 pounds and a payload of 5000 pounds and was the true predecessor of the C-47. There were follow-on versions of the C-47 built after 1941 by Douglas, from the C-48 to the C-53 airplane.

At this time, 1941, the Air Force published requirements for an airplane of 50,000 pounds gross weight, a payload capability of 10,000 pounds, and a capacity for 56 places. This was met by the Curtiss-Wright C-46, using two P&W R-2800-43 engines.

The next significant point of development was the C-54 built by Douglas in 1942, at 65,800 pounds with a payload capability of 8000 pounds. This aircraft was built to carry 56 passengers and powered by four Pratt & Whitney R-2000-3 engines. It was a direct militarization of the civilian DC-4A SKY MASTER. Other versions of the C-54 were later developed to take-off gross weights of 73,000 pounds and 9,100 pounds of cargo. This development was a significant point in Air Force air transport capability.

The next step in the advancement of the transport was the Model 4910 "Constellation" develcped by Lockheed. This aircraft was procured by the Air Corps in 1942 at a take-off gross weight of 82,000 pounds with four Wright R-3350-35 engines. It had a capability of 69 passengers. However, later versions of this aircraft at 86,000 pounds gross weight (13,300 pound payload) carried as many as 100 passengers.

There were no further increases in gross weight and size of aircraft until the Douglas C-74 at a gross weight of 145,000 pounds, 30,500 pounds of payload and capacity to carry 129 passengers and crew members. What made this size increase possible was the development of the larger air-cooled engines by the Military Services. The GLOBE MASTER C-74 was powered by four Pratt & Whitney R-4360-27 engines. The commercial version of the C-74 was the DC-7. The aircraft was developed for delivery in 1942; however, major deliveries did not take place until 1946.

Another comparable sized aircraft of the large transports was the C-97, built by Boeing and delivered in 1945. This airplane had a take-off gross weight of 140,000 pounds (35,000 pounds payload) and carried a total complement of crew and passengers of 134. The industry development of this aircraft, called the Boeing Model 377, came primarily from the development of the B-29 and B-50 aircraft. It was also powered by four Pratt & Whitney R-4360-20 engines.

The next milestone in transport aircraft was the XC-99. This aircraft funded by the Air Force made a significant advancement in size in that it had a 265,000 pound take-off gross weight, a payload of 76,000 pounds and was designed to carry 400 passengers. This transport was a conversion to a transport of the B-36 airplane. It was a significant event (1946) and increased the number of engines in an aircraft from four to six.

(2) Flow of Technology

The undertaking of the development of transport aircraft was initially done by the industry and later by the Air Corps. Industry took the lead in building aircraft to carry a small number of passengers and haul mail, while the Air Corps had need of cargo hauling and air evacuation. Throughout the past forty years there has been an interplay between transport aircraft for the military and those being built for civilian use. In the 1930's, the aircraft industry had a definite lead in transport aircraft, primarily the Douglas DC-2's and DC-3's and later the DC-4A, the SKY MASTER. These aircraft were forerunners of many versions of the military cargo and transport aircraft. Lockheed Aircraft Company also had a commercial version, the 12-A which became the Air Corps C-40.

However, the greatest quantity of airplanes built by the Air Corps were direct versions of the DC-2s and DC-3s. These were such aircraft as the C-32, C-33, C-39, C-47, C-48, C-49, C-50, and C-53.

The Army Air Corps began to make their inroad into the cargo and transport fields with the Curtiss-Wright C-46 in 1941 and the Fairchild C-82 in 1945. At this point, the aircraft designers of cargo and transports were closely coordinating their efforts. However, the military requirements for carrying larger cargo payloads began to surpass civilian needs when the Air Force established a requirement for a 145,000 pound cargo airplane with a payload of 30,000 pounds. This resulted in the Douglas C-74 in 1946. The airplane made a significant advancement in the size of aircraft that was made possible by the military development of the Pratt & Whitney R-4360 engines. At this time, the technology began to flow from the military to the civil side, with the commercial version of the C-74, the DC-7. Improved versions of the C-74 were the C-124s and these were designed at gross weights of 185,000 to 205,000 pounds. The payload was about 55,000 pounds. This aircraft definitely showed the trend for heavy logistics support required by the military. The technology flow was definitely from military to civilian.

The next major undertaking, in 1954, was the Boeing C-135A developed by the Air Force at 279,500 pounds with a payload of 76,900 pounds. This jump was made possible by the availability of jet engines. The military requirements were for aeromedical evacuation and refueling. The commercial transport version was the Boeing 707. At this time, the technology was being used across the board by either industry or the military.

When the C-124 cargo aircraft showed the potential of carrying 60,000 pounds of payload, the Air Force saw the need for more expeditious handling of large cargo shipments. On 18 June 1956, the Commander of the Air Materiel Command requested Hq USAF, Chief of Staff, to form an Ad Hoc Committee to examine the problem of modernizing and streamlining the Air Force air-freight system. As a result of this, the USAF published General Operational Requirement (GOR) No. 157 on 8 March 1957. This document defined, for the first time, all elements of an aircraft cargo handling system which required simultaneous development, standardization and implementation. Further, the study was to include recommendation for standardization of methods and techniques to be employed in packaging, marking, documenting, and handling air freight. Following this action, on 29 May 1959, a contract was let with Douglas Aircraft Company for $750,000 (Contract AF33(600)-39338). The purpose of this effort was to define in detailed procedural terms a complete cargo handling system.

Following the Douglas study, other contracts were let in August 1960 for an Aircraft Loading System and 40,000 pound Mobile Loaders for C-124, C-130, and C-133 and Logair.

(3) Civil Aviation Benefits

Throughout the past forty years benefits have been gained both by civilian aviation and the military from efforts undertaken in civilian industry. In early days of development, practically all developments generated by civilian industry were used for military purposes. However, the increasing requirements of military operations led to growth of aircraft size and payload-carrying capability. It was at this point that civilian aviation began to benefit.

The work on cargo handling progressed rapidly and an inauguration ceremony was held on 29 March 1962 at Travis AFB, California, where Lt. General Joe W. Kelly, Commander, MATS, called the Air Force air cargo system the most modern material handling system in the United States. Civil aviation began to become aware of this problem for the large cargo aircraft to come. Cargo handling for civilian aircraft made use of packaging, documenting, and some of e loading and unloading equipment. It required 2-3 years for the civilian sector to gain the benefit of the Air Force cargo handling development. It represented a savings to the civilian sector of about $50.0 million.

(4) Subsequent Development

One of the major R&D accomplishments used by the builders of large swept-back wing transport aircraft was the development of the high bypass ratio turbofan engine. This development has permitted conventional configurations without too many engines. As one can recall the Hughes HK-1 built in the early forties (financed by the Reconstruction Finance Corporation) used eight R-4360 engines. Perhaps this design would have benefitted if large power packages had been available.

The requirement by the Air Force in 1961 for an airplane of the 700,000 pound class led to the development of the Lockheed C-5A. Major technology programs were undertaken by the military to develop this airplane. These programs had a major influence on the development of the wide-body airliners.

(5) R&D Costs

From a review of industry IR&D documentation, an estimated 25 million dollars a year is being expended by industry. Of this, 50% or better, is supported by DoD. Advanced Development Programs by

the Air Force in the areas of materials (including composites), propulsion systems, flight control for automatic landing, and equipment are current. It is estimated that 500 million dollars a year is being expended in direct support of large aircraft. For cargo handling, the initial contracts were for 2.5 million dollars.

In 1960 Hq USAF had programmed funds for the Cargo Handling System to the amount of 4.9 million dollars for R&D efforts and on 5 May 1960, 79.201 million dollars were allocated for production. These funds were expended up through FY 66.

The total R&D funds were 7.5 million dollars for the cargo handling program.

SECTION II-G
DESIGN HANDBOOKS AND SPECIFICATIONS FOR AIRCRAFT DESIGN

I. INTRODUCTION

The programs undertaken to develop design guides are of fundamental importance to aeronautical system design. Many of the military design guides are rewritten for use in civilian aviation. In military activities, these specifications are adhered to or deviations are requested. In total, these provide a current authoritative source of design information in support of the definition, validation, design, and development of military systems and equipment. Throughout the years these documents provided a continuously advancing base line for each new generation of airplanes conveying proven techniques and precluding, or at least minimizing, repetition of past errors. These efforts have been, to a great part, a compilation of experience by the whole of military, civil, and industry in aircraft design. Future activities in these areas will continue. However, the strict application of specifications may not be adhered to if private industry can prove to themselves and to the government that better design approaches can be taken. In this field of work the significant activities are the design handbooks, military specifications, military handbooks, Federal Aviation regulations and the activities of technical committees composed of representatives of industry and government.

II. SIGNIFICANT ADVANCES SINCE 1925

The Design Guide Program has evolved through the past fifty years in response to rapid changes occurring in military requirements and aircraft technology. The major advances are gradual and are generated through improvements in design to meet the demand for

expanded flight profiles, increase in speed and increase in size of aircraft systems.

(1) Early Developments

The design handbooks started as far back as 1919 and were referred to as "Guides to Design". Soon after, they became the "Handbook of Instructions for Aircraft Designers" and later became "AFSC Design Handbooks". This program has continued throughout these years and has now developed into one consisting of a series of handbooks. These cover design criteria from personnel subsystems, environmental engineering, aerospace materials to airframe design and electronics and communications systems. During the days when the Army Air Corps organization, the Air Materiel Division accomplished this work, much of the ground and flight testing was accomplished at Wright Field; therefore, this became the place where the documents were compiled and made available to all of the aircraft industry.

In the development of design handbooks and specifications for aircraft designs, the first advance is the transition from the Air Force's "Guide to Design" initiated about 1919, to the Handbook of Instructions for Airplane Designers in February 1920. The second major advance was the publication of the AFSC Design Handbook series in 1967.

(2) Flow of Technology

Many revisions were made to the USAF design handbooks and an enormous distribution has been accomplished throughout the years. The present records show that the distribution of AFSC Design Handbooks is 40% (15,034) copies to government agencies and 60% (22,551) copies to industry.

Much can be said about the national aviation industry in generating design data from research, lessons learned in design, test and operational experience. During the past forty years the military, civil, and industry have participated in technical committee meetings to exchange design data and experience so that reports could be prepared for the designer. These committees are the AIAA, the Advisory Committees of NASA, ASWE, ASME, and SAE. For example, the Society of Automotive Engineers (SAE) committees are involved in areas of major importance to aircraft engineers. There are five major aerospace divisions and at least 32 panels. The committees are made up of technical personnel in government and industry whose prime purpose is to arrive at a common goal for design advancement and standardization of major aircraft elements. The military have participated in these committees and provided technical data derived from design and test programs which were necessary to arrive at significant design

decisions for both military and civilian aircraft. Some of these committees are in the area of aircraft shock and vibration; aircraft equipment; aircraft environmental systems; airplane control; aircraft landing gear systems; aircraft fluid power and control technology, and others.

(3) Civil Aviation Benefits

These military handbooks are of enormous benefit to civilian aviation. In many cases the civilian aviation has applied particular sections of the design handbooks to their own use in their design standards. Federal Aviation regulations refer to these handbooks in parts of their regulations. For example, in Air Worthiness Standards, Transport Category Airplanes, under material strength properties and design values the following statement is made:

> "Unless they are shown to be inapplicable in a particular case, the design values must be those contained in the following publications (obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., 20402): MIL-HDBK-5, "Metallic Material and Elements for Flight Vehicle Structure"; MIL-HDBK-17, "Plastics for Flight Vehicles"; ANC-18, "Design of Wood Aircraft Structures"; and MIL-HDBK-23, "Composite Construction for Flight Vehicles"."

Another example is in the area of Brake Design, particularly anti-skid devices, where the following statement is made:

> "If antiskid devices are installed, the devices and associated systems must be designed so that no single probable malfunction will result in a hazardous loss of braking ability or directional control of the airplane. Antiskid devices meeting the air-worthiness portions of Military Specification MIL-B-8075 (ASG) and any amendments thereto, are acceptable."

The MIL-A-008860A series of Military Specifications on Airplane Strength and Rigidity which covers flight loads, landing and ground handling loads, miscellaneous loads, ground testing, vibration, flutter, divergence and sonic fatigue is another example of the many specifications applied directly to civilian aircraft design.

(4) Subsequent Development

As major advancements are made in technology and in the operational refinements of aircraft, the various design handbooks, specifications and criteria are updated. A major amount of this work

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is accomplished by DoD. One example is the proper consideration of the airplane noise problem. During the development of the KC-135, the Boeing Company undertook a noise program for jet aircraft. This was a military aircraft; however, the interior sound levels had to be determined and soundproofing treatments applied. Design data were generated in accomplishing this effort and these then became available for control of noise in other aircraft. The experience gained from this work and the results published were then applied to the control of interior noise in the 707 and 727.

(5) R&D Costs

It is very difficult to isolate the R&D investment to support design handbooks, specifications, and other design criteria. Over 2 million dollars have been expended by the USAF in the past ten years to compile the data and publish the Design Handbooks. The effort to generate the data for the documents is very extensive and is spread throughout the military and civilian aerospace industry. Much of the design data is obtained during the R&D programs of the government laboratories and specific aircraft system development programs.

The cost to the civilian aviation sector if the R&D investment had not been made by the military is estimated to be many millions of dollars.

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SECTION III
CURRENT AND PLANNED R&D EFFORTS

The objective of this Section of the report is to examine the scope of aeronautical R&D presently planned or funded by U.S. civil government and military establishments and to determine probable transfer of technology to the civil sector of aviation, and to show what commercial aviation is developing under their own auspices which is applicable to military development needs.

The current and planned R&D efforts are presented in the same groups as was done in the preceding Section II of the report, i.e., (A) Flight Mechanics, (B) Structures, (C) Flight Control, (D) Vehicle Dynamics, (E) Vehicle Equipment, and (F) Aircraft Developments.

SECTION III-A
FLIGHT MECHANICS

Programs are detailed in this section for the eight significant advances in Flight Mechanics. For convenience, these are repeated here: (1) High Lift Devices, (2) Aerodynamic Drag Reduction, (3) NACA Airfoil Series, (4) Swept Wing, (5) Delta Wing, (6) Variable Sweep Wing, (7) Supersonic Airplane, and (8) Aircraft-Propulsion System Integration. As indicated in the introductory paragraph of the preceding section (II-A), the R&D programs described have evolved over the years from the original events indicated by the titles.

A-1. High Lift Devices

(1) Government

a. Air Force

High lift mechanical and fluidic devices (leading edge and trailing edge flaps, slats, jet flaps, etc.) for landing, take-off, transonic maneuvering and cruise are being investigated and improved, as well as advanced flight control devices which will be highly effective in the transonic regime. A comprehensive analysis of buffet onset/growth data, which was acquired during recent Air

Force buffet flight test programs, is providing an insight into the details of the buffet phenomena for a variety of wing planforms and sweeps, which will provide technology for delay of buffet during cruise and maneuvering. Several programs address the problem of transonic buffet and the means to delay its onset and reduce its intensity in order to develop design criteria for high-lift combat maneuvering. Flight demonstration of the supercritical wing technology using the TACT F-111 is to be performed in June 1973.

b. Navy

Programs being conducted by the Navy address both the problems of predicting supercritical (mixed subsonic-supersonic) flow about bodies, and development of improved wing-body blending to achieve high efficiency in transonic flight. Extensive design and wind tunnel tests of a blended supercritical wing/body on a modified T-2C have been tested in flight and tests on an F-8 model are scheduled through 1973.

c. NASA

NASA technology programs have progressed to the point where flight tests for proof of concept and more detailed flight programs to develop design and certification data as well as operational data related to STOL systems of interest to civil and military applications and critical to decisions related to design and development of operational systems are warranted. Current NASA programs on STOL aircraft technology are given in Section III, F-1, b on page 177.

(2) Commercial

a. DoD-Sponsored IR&D

Independent Research and Development work within industry, in the areas of transonic flow predictions, improved airfoils, and wing/body blending is actively being pursued by almost all major aerospace contractors, and applicable to both military and commercial transport aviation. Computational techniques being emphasized by Convair/General Dynamics and Lockheed are aligned to numerical solutions, and North American Rockwell is stressing an analytical solution approach. Advanced concepts in externally and internally blown flaps, ejector lift/cruise flaps, and BLC devices are also being investigated under DoD IR&D, and results will be of mutual benefit to civil and military aviation.

A-2. Aerodynamic Drag Reduction

(1) Government

a. Air Force

Drag prediction methods are continually being updated as improvements are developed. Generalized aerodynamic prediction techniques are being developed for the complete design and performance of aircraft. Both theoretical and experimental investigations of supercritical airfoil characteristics are being conducted. One of the investigations includes the effect of a jet flap on a supercritical airfoil. Studies are being conducted to determine detailed needs for high Reynolds number testing. Several wind tunnel-to-flight correlation studies are being conducted and planned by the Air Force to arrive at accurate prediction methods. These include experimental studies on the C-5A, FDL-8, and F-4 models. Programs are being conducted in transonic test techniques to develop technology for obtaining more accurate wind tunnel test data. Primarily through the C-141 and C-5A development test programs, the Air Force found that the major factor affecting the limitations of data applicability was testing techniques in transonic facilities. A recent NASA-AF ad hoc group has assessed the areas where special emphasis needs to be placed to improve the accuracy and thus the reliability of wind tunnel facilities. Reynolds number effects on semi-span and full-span models have shown large comparative anomalies. Studies are being conducted to determine the sources of the anomalies since semi-span type models have certain technical and economic test advantages. The relationship between unit Reynolds number and the Reynolds number based on the length of run for boundary layer transition has been found to be strongly influenced by facility-generated disturbances. Data from investigations using a 10° transition cone in different tunnels is being evaluated to determine specific effects. A flight test of this cone on the front of an F-4 is being proposed to obtain disturbance-free, wall-free transition data. Studies are being conducted and planned to determine the effects of the transonic wind tunnel walls and the dynamic disturbances. These will lead to improvements in existing facilities and advanced designs for new facilities.

b. Navy

In addition to basic shock/boundary layer interaction investigations, the Navy is studying methods of integral relations for development of transonic airfoil sections. Supporting transonic wind tunnel tests, and associated two-dimensional test techniques development, will be performed at the NSRDC. Wing/body optimization research is also proceeding.

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c. Army

The Army is presently conducting research on analytical and experimental methods for controlling boundary layers and shock-induced separation on transonic airfoils with emphasis on rotary wing aircraft applications. Significant advances in the basic analytical techniques for solving transonic flow around bodies of revolution have been achieved by the Missile Command. These, and planned research in this area will support the analytical aerodynamic techniques utilized in transonic aircraft technology.

d. NASA

Numerical methods for predicting transonic inviscid flows, including imbedded shocks, have been developed which apply to the practical design of minimum drag transonic cruise aircraft. Configuration optimization studies are being performed. Airfoil development programs have resulted in the supercritical wing concept which promises economical cruise speeds near sonic velocity. Wind tunnel testing techniques, scale effects, data extrapolation, and correction procedures are being investigated in a program coordinated with the Air Force and Navy. Advanced wind tunnel facilities, such as the high Reynolds number Ludweig Tube, are being developed. Wind tunnel/flight data correlation and verification of supercritical wing technology are being achieved by flight tests of a modified F-8. The transonic analysis and test research efforts by NASA have been effectively integrated into their Advanced Transport Technology Program which will provide the base for the next generation civil aviation transports.

(2) Commercial

a. DoD-Sponsored IR&D

DoD-sponsored IR&D work with industry involves the complete spectrum of transonic technology, much of which is applicable to both military and commercial transport aviation. Analytical and numerical techniques for planar transonic flow field analysis have been pursued by all major airframe contractors, with notable successes by General Dynamics, Lockheed, North American, and Boeing. All contractors are continuing to refine and improve their computer-aided transonic wing and vehicle design programs based on extensive analytical and experimental investigations. McDonnell-Douglas has investigated transonic wind tunnel wall corrections and test techniques including wind tunnel/flight test correlations.

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A-3. NACA Airfoil Series

(1) Government

a. Air Force

Efforts are underway in developing accurate aerodynamic predictions for rapid analysis of complete configurations and in developing modular prediction methods that allow detailed analyses in specific areas. The following modular prediction methods are being developed or refined: (a) boundary layer analysis, separation prediction, and resulting skin friction and pressure drag; (b) drag prediction methods for complete configurations; (c) drag due to lift prediction at high angles of attack and transonic Mach number; (d) drag prediction of external stores; (e) advanced airfoil pressure distribution method which includes wing-body interference.

b. NASA

NASA aerodynamic prediction methods effort is concentrated in finite element aerodynamic models for predicting pressure distributions of complete configurations in the subsonic-transonic and supersonic regimes. Extensive supersonic flow analysis capability was developed to support the supersonic transport optimization. Continued work in non-linear supersonic prediction methods will support configuration optimization of future transonic and supersonic transports.

A-4 & 5. Swept Wing and Delta Wing

(1) Government

a. Air Force

A technology advance which will significantly extend the range of future subsonic and transonic transport aircraft is boundary layer control. This will reduce wing separation, keep the flow attached, and provide a substantial reduction in wing drag. The jet flap, slot blowing, and vortex generator concepts are all being actively pursued and offer aerodynamic improvements which can be applied to extend the range of advanced commercial transport systems. The jet flap can provide up to 90 percent thrust recovery for improved cruise efficiency, and technology for improved vortex generators will be developed by 1974. The slot blowing concept, an augmentation to the jet flap, should be available for application by 1975. The lift cruise ejector is being developed to improve both take-off and cruise efficiency. This concept will be developed by 1974 and will have direct application to future commercial transport systems. The supercritical airfoil concept developed at NASA

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Langley Research Center is being utilized in the design of a new wing for improved transonic performance to be demonstrated on an F-111 aircraft in 1973-1974.

Additional supercritical wing development efforts to be investigated in 1972 include blended wing-body configurations and high aspect ratio wings which utilize advanced composite materials to provide further improvements in both subsonic and transonic flight. The aerodynamic improvements being investigated, and in many cases demonstrated through flight test, will result in 35 percent increase in subsonic (L/D) max., 20 percent increase in transonic Mach number before drag rise, 45 percent increase in cruise range efficiency, and 30 percent reduction in drag increment due to propulsion system operation.

b. Navy

One concept that has application to subsonic-transonic transport airplanes is the supercritical airfoil of increased thickness that avoids the reduction in drag-divergence Mach number that is incurred in conventional airfoils by increase in thickness ratio.

c. NASA

NASA has extensive research efforts which have application to commercial transport aircraft. The Advanced Technology Transport (ATT) is a sizable effort currently being pursued. The configurations developed will utilize the most recent advances in the state of the art such as the supercritical airfoil, which is being tested on a modified Navy F-8.

(2) Commercial

a. DoD-Sponsored IR&D

IR&D work in the area of range extension applicable to both military and commercial transport aviation includes efforts to develop the jet flap concept, advanced wing/body blending for large transport type aircraft and improved analytical techniques, numerical as well as exact mathematical, for predicting transonic aerodynamic characteristics.

A-6. Variable Sweep Wing

(1) Government

a. Air Force

The Air Force is currently evaluating the F-111 airplane to determine the problems encountered with an operational variable geometry system. The B-1 bomber, which is under development, will provide additional technology on large variable geometry systems.

The Air Force in a joint program with NASA, will evaluate the supercritical wing used in conjunction with a variable geometry system. Mid 1973 is the projected flight test date. Low level efforts are underway keeping pace with the potentials of variable twist and camber.

b. Navy

The Navy is actively evaluating the F-14 airplane. This program represents the first application of variable geometry on the new high performance-highly maneuverable air superiority fighter configurations. The aircraft has several unique features, including retractable foreplanes to minimize aerodynamic center travel.

c. NASA

NASA has extensive efforts in many facets of variable geometry. The programs extend from developing an understanding of basic fluid mechanics problems to flight test of various concepts to demonstrate the usefulness of the hardware resulting from the research.

(2) Commercial

a. DoD-Sponsored IR&D

IR&D work is continuing on variable geometry concepts, with particular emphasis on methods used to obtain high lift coefficients.

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A-7. Supersonic Airplane

(1) Government

a. Air Force

Investigations in the area of high speed vehicles for such potential military applications as air defense, strategic offense, reconnaissance and surveillance, are being conducted. Efforts have been directed at evolving a sound technology base in aerodynamics, heating, inlets, nozzles, materials, structures, flight control and configuration definition.

Preliminary conceptual design studies have defined the general aerodynamic configurations for hypersonic flight. The general technology being developed would have application to commercial advanced transport systems. Wind tunnel tests have been conducted on a series of airbreathing high speed cruise configurations to define the aerodynamic, stability and control characteristics. Critical technology problems have been determined in each of the technical disciplines. A hypersonic test vehicle configuration has been extensively investigated to define the technologies essential for sustained hypersonic speeds. Specific efforts are being conducted to predict accurately the aerodynamic heating environment for high speed vehicles. Of particular importance are regions of interference heating, shock wave impingement and boundary layer transition. Efforts are planned in 1973 - 1974 to perform a conceptual design and experimental investigation of a modular incremental growth test vehicle. The growth test vehicle will be designed to systematically explore the hypersonic flight regime in incremental steps. The primary modifications required to the vehicle as it progresses in speed from transonic to high hypersonic speeds will be the thermal protection system and propulsion system. This will provide the necessary technology for the development of both military and commercial high speed vehicles. A wealth of design data on high speed configurations has been generated from extensive studies on high performance lifting entry vehicles, including ASSET, PRIME, and X-24A. These have demonstrated radiative materials, high temperature structures, aerodynamic and stability prediction methods, flight control system, and landing and handling characteristics of high speed vehicles. The Air Force X-24B will demonstrate subsonic, transonic and supersonic flight characteristics of a high speed configuration.

b. Navy

The Navy Advanced Deck-Launched Interceptor pre-design study contributed to civil aviation through investigation of next generation aircraft configuration, advanced structure and related subsystems. The Maneuvering Hypersonic Vehicle Configuration design study of lifting reentry vehicles contributes to civil aviation through investigation of high heat load structures and attendant thermal protection system designs.

c. NASA

The current NASA programs on hypersonic research and transport vehicles will have direct application to civil aviation. These efforts encompass aerodynamic definition of many configurations over the Mach range 0.2 to 12 in experimental test facilities, aerothermoelastic structure designs, advanced air-breathing engine designs with attendant configuration influence caused by inlet and nozzle integration, and which use hydrogen fuel with low pollutant emissions. These vehicles will give rise to a large range of avionics gear which will be directly applicable to fast moving civil aircraft to accomplish control, safety, navigation and guidance functions.

(2) Commercial

a. DoD-Sponsored IR&D

IR&D activities, while chiefly intended for military applications have near-term civil aviation applications. The high speed vehicle IR&D has developed new materials for high temperature application such as titanium, coated columbium, reusable surface insulation, etc.; new highly versatile lightweight flight control system such as fly-by-wire; new lightweight heat exchangers for active cooling systems; improved understanding of aerodynamic and aerothermodynamic effects of vehicle surface discontinuities; configuration development for aerodynamic flight over a wide range of Mach numbers.

A-8. Aircraft-Propulsion System Integration

(1) Government

a. Air Force

Efforts are being directed at the optimization of the subsonic, transonic, and supersonic classes of vehicles and will

evolve general technology that will be applicable to various commercial aircraft systems including transport and V/STOL applications. Particular programs for these vehicles that will be completed by 1973 - 1975 include: (1) development of exhaust nozzle designs for optimum internal and external performance; (2) documentation of exhaust nozzle/afterbody drag characteristics; (3) development of inlet drag and performance characteristics; (4) development of analytical methods for the accurate predictions of aircraft performance capabilities; and (5) development of inlet-engine distortion sensitivities and assessments of installation compatibility. Portions of all of these programs are applicable to the development of any advanced technology commercial aircraft system which requires increased performance capability such as range and payload.

b. Navy

The Navy is also conducting research in the development of analytical methods applicable to the prediction of aircraft performance capabilities, which has application to any aircraft system. Other Navy efforts are being directed toward development of VTOL aircraft technology which again could have a direct impact on development of commercial systems.

c. NASA

NASA is currently investigating various aspects of the propulsion system integration problems through analysis as well as wind tunnel and flight tests. Due to NASA's involvement with current commercial applications, many of these efforts are directly applicable to future commercial aircraft applications. Some of the present NASA efforts, involving wind tunnel and flight tests of various aircraft (e.g., Harrier, YF-12), seek to identify some of the performance characteristics of various configurations as well as for development of refined analytical procedures. Development of the Advanced Technology Transport will necessitate the investigation of high performance low drag propulsion system installations. Within this effort, extensive development of analytical procedures are being accomplished. These procedures and associated test results should have direct application to various future aircraft systems. NASA is also continuing the study of propulsion system components applicable to V/STOL systems. A Propulsion System Installation Evaluation Program employing flight tests of the C-5A, which will provide valuable propulsion system data for most subsonic transport applications, is also planned.

d. Army

The Army's program is primarily concerned with the ingestion problem of rotorcraft. Efforts include screens and

various types of separators. The intent is to reduce the ingestion that is detrimental to the structural aspects of the engine without any degradation in engine performance. The severe operating environment that Army aircraft are required to perform requires lightweight inlet devices that are efficient in eliminating damaging foreign object ingestion.

(2) Commercial

a. DoD-Sponsored IR&D

DoD sponsored IR&D work within industry addresses all aspects of advanced propulsion system development including system design, test, optimization and integration that are applicable to both military and commercial systems. Included are developments of such items as: time dependent flow field analysis procedures by General Dynamics and Grumman; development of propulsion system performance and drag assessment test procedures for aircraft by McDonnell and Boeing; development of inlet and nozzle analysis procedures by Lockheed; development of exhaust nozzles for noise reduction by Pratt and Whitney; and development of thrust reversers by Rohr.

SECTION III-B
STRUCTURES

R&D programs are detailed for the significant advances in Structures: (1) Stressed Skin Metal Airframe, (2) Weight Control, (3) Fatigue Testing, and (4) Fibrous Composite Structures. These titles which attempt to name important past events or initial bench marks in aviation progress, may not be fully indicative of the nature of present-day R&D. Thus, stressed skin structure research has evolved into advanced structural analysis and optimization. With this explanation in mind, the current and planned R&D described in this Section can be more readily associated with the event that initially inspired it.

B-1. Stressed Skin Metal Airframes

(1) Government

a. Air Force

Efforts have been directed during the 1960 time period toward the generation and development of two large finite element general purpose computer programs "MAGIC" and "FORMAT". These programs are in open distribution and are being periodically modified to increase their capability. In 1971, eight new elements will be added to the library of "MAGIC". These two programs are in current use in the aerospace industry for designing both military and civil aircraft. The most current example is the DC-10 which was analyzed using FORMAT.

A report on the evaluation of methods for analyzing shell structures will be completed in early 1972. The development of methods for the optimization of structures has accelerated through the application of optimality criteria. The Air Force "ASOP" (Automated Structural Optimization Program) completed in 1971, has found wide acceptance throughout the aerospace industry for preliminary design. This extremely efficient program will be extended in 1972 to include compression panel optimization. The feasibility of using optimality criteria with a large general purpose program will be established in 1972. The development of efficient optimization methods that will consider both strength and flutter constraints will be initiated in 1972.

b. Navy

The Navy is maintaining a strong capability in structural design through careful selected procurements of recent improvements and innovations in structural analysis methods. As program director for an ARPA funded contract, the Navy is pursuing an extensive program of wide applicability in interactive computer graphics.

c. Army

The Army is extending methods for predicting the dynamic response and transient aeroelastic response of rotor systems and V/STOL vehicles. Additional areas being investigated include Moire method of beams and vibration damping of light structures.

d. NASA

NASA has been actively developing a large general purpose computer program called NASTRAN. This program has operational modules for static stress and deflection, buckling, vibration modes and frequencies and transient response. This program updated annually, is completing its second updating in 1972. The scheduled improvements will include new elements, a heat transfer module, substructuring and an increase in computational efficiency. NASA is initiating a program, IPAD (Integrated Program for Aerospace Vehicle Design) which will integrate computer methods from various disciplines (aerodynamics, aeroelasticity, propulsion, weights, and structures) into a single cohesive system for automation of a substantial portion of the design process. The feasibility studies will be completed in 1973 and followed by development of an initial level program which should be available in 1975.

(2) Commercial

a. DoD-Sponsored IR&D

DoD-sponsored IR&D work consists almost entirely of updating their computer methods with DoD and NASA-sponsored developments.

B-2. Weight Control

(1) Government

With regard to aircraft weights, the government is not very active in development of further aircraft weighing techniques and center of gravity computations. There is a small amount of effort within the Air Force on development of weight and weight/cost prediction. Recent past work was associated with Level-I weight estimation, initial estimation techniques based solely on statistical data from past systems; current effort is being conducted on a refined Level-II weight estimation procedure which allows the inclusion of the impact of weight for advanced structural concepts and materials applications.

(2) Commercial

a. DoD-Sponsored IR&D

Current R&D efforts are being conducted by industry primarily in the area of weight prediction methods. These efforts are to develop and implement improved methods consistent with technology development and sensitivity to design criteria of structure, propulsion systems, and aircraft configuration. These methods are usually to be integrated with present methods for distributing the weights of the aircraft propulsion vehicle and payload masses for compatibility with wing placement and center of gravity position limits and for empennage resizing if required. Primarily, the weight prediction improvements are being made to airframe and systems weights, to expand the capability of the low aspect ratio wings, to develop a capability for evaluation of weights for various airload distribution and to integrate improved allowable stress methods into weight prediction systems. For civilian application, these weight improvement methods support new airplane studies for transports, and STOL aircraft.

b. Company Funded

The major activities in Industry (commercial) are in the areas of developing new approaches to integrated weight and balance systems. These efforts are private ventures and proprietary.

B-3. Fatigue Testing

(1) Government

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a. Air Force

Work examining the effect of random loading, stress level, block size, and loading sequence on fatigue life will be complete in 1973. The initial work on the annealed foil fatigue sensor to be used in measuring life will be completed in 1972. This work is being extended to include the development of a new sensor utilizing vapor deposition of the sensor as opposed to current bonded-on-foil sensors. These gages are undergoing flight evaluations on the C-130 and T-37. The experimental and analytical effort to establish an improved method for calculating fatigue life using Neuber's fatigue analysis techniques will be completed in 1973 Programs to establish the validity of fatigue test time compression for supersonic aircraft will be completed in 1973.

The reports, AFFDL TR 69-100, "Fracture Mechanics Guidelines for Aircraft Structural Applications", and AFFDL TR 70-144, "Proceedings of the Air Force Conference on Fatigue and Fracture", clearly consolidated at that time the state of the art in fracture mechanics for the entire aerospace industry. A new fracture mechanics design and analysis handbook will be completed in 1972 and will be updated annually. A survey of engineering methods for the design and analysis of damage-tolerant structures will be completed in 1972. The application of finite element methods to fracture analysis will result in a capability to analytically determine stress intensity factors for two and three-dimensional structural assemblies with flaws and local plasticity. The two-dimensional phase will be completed in 1973 and the three-dimensional effort in 1975. Methods for predicting plane stress and mixed mode fractures which will include the effects of plasticity, geometry, strain rates, and buckling will be completed in 1975. Another problem is investigating the behavior of flaws originating at fastener holes. A very comprehensive experimental program is being conducted to supply basic stress intensity data, crack growth rates, crack arrest data for aluminum, titanium and steel and other substantiating data for the above analytical effort.

b. Navy

Combined theoretical and experimental programs in 1972 and 1973 will yield improved methods of fatigue life estimation. The experimental programs will include the effects of load spectrum, block size, stress level, sequence, fasteners, and corrosive environment.

c. Army

Extensive programs in fatigue and fracture that are directly applicable to the helicopter and V/STOL class of aircraft are being pursued. Programs scheduled for completion in 1973

include the effect of corrosive environments on rotor hubs, rotor blade failure analyses, and experimental fatigue tests of composite rotor blades.

d. NASA

Fatigue programs on hot structures include a simulation of a supersonic transport operational load and thermal environment in both compressed and real time. Other programs include the fatigue life of structures reinforced with composite materials and the development of an airborne strain counting device as a fatigue life indicator. The fracture program includes a number of crack propagation studies for investigating the effects of high stress levels, multi-layered plates and shells, plane stress fracture and interference fit fasteners.

(2) Commercial

a. DoD-Sponsored IR&D

The Independent Research and Development work in fatigue and fracture is normally restricted to programs peculiar to the company's military and civil aircraft and to evaluate new structural concepts.

B-4. Fibrous Composite Structures

(1) Government

a. Air Force

An extensive program for the development of composite structures utilizing advanced high strength, high stiffness fibers has been underway since 1964. The major portion of this effort has been directed toward epoxy matrix systems that have a temperature capability to 350°F and which have application on subsonic to Mach 2 aircraft. A much more limited effort is being conducted for polymer and metal matrix systems for use at higher temperatures. It would be applicable to supersonic aircraft. This technology is fully applicable to any aircraft regardless of its operational use. Military requirements often impose more severe design criteria than commercial requirements. Thus, use and substantiation of composite materials on military aircraft enhances the reliability when used in commercial aircraft. All aspects of design, manufacturing and operational use that are necessary to make structural composites a mature technology are being addressed. Demonstration of the technology is being accomplished through building and performing ground structural tests on scaled and

full-scale components and through flight testing experimental articles. Also, operational service flight testing of production structural hardware is being noted. Work on the structural dynamics properties is addressed in D-1a, Page 158.

b. Navy

This work is directed almost exclusively toward structural hardware using graphite filaments in an epoxy matrix. The boron/epoxy horizontal tail on the F-14 will be their first production component and is now seeing service use on the flight test fleet and should begin operational use in late 1973.

c. Army

The programs emphasize application areas significant for helicopters and V/STOL systems. While all areas of materials, design and manufacturing are being covered, funds appear to be very limited relative to other government agencies.

d. NASA

NASA efforts, until recently, have been exploring the feasibility of selectively reinforcing a metallic substrate structure with unidirectional composites to achieve the most optimum weight and cost advantage. This approach offers the greatest prospect for the earliest acceptance by the industrial design community for composites. The contemporary composite technology has been extensively broadened and intensified by efforts in support of the Space Shuttle. Some of these tasks are for applications beyond the temperature range of epoxies. For the Shuttle, developments in filament wound pressure bottles and in cryogenic tanks are being conducted using advanced composites.

(2) <u>Commercial</u>

a. DoD-Sponsored IR&D

Composite structural research and development are receiving considerable attention in many IR&D efforts. These programs are based in the areas of materials development, design and manufacturing technology. The product line of each company has a strong influence on the technical orientation of these developments. Almost all programs include full-scale hardware developments and laboratory evaluation testing. Some flight test hardware has been and will continue to be developed.

SECTION III-C
FLIGHT CONTROL

These programs are detailed for the three significant advances in Flight Control Technology: (1) Blind Flying and Instrument Flying; (2) Autopilot and Automatic Flight Control; and (3) Load Alleviation and Mode Suppression.

C-1. Blind Flying and Instrument Flying

(1) Government

a. Air Force

The Air Force is deeply involved in efforts that are concerned with capability to land aircraft under all weather conditions. Experience has shown that virtually all of the technology advances of the military in this technical area find their way rapidly into civil aviation use. A prime example is the fact that the system developed by the Air Force for tactical use in Southeast Asia has become the first microwave landing system commissioned by the FAA for use by a commercial airline. This occurred in 1971 at Fullerton, California, where Golden West Airline has been certified to use TALAR IV, the system developed and presently being procured in production qualities by the USAF, for low visibility (ICAO Category I) landings.

Air Force exploratory development programs in all weather landing is to develop new techniques for flight path control particularly to overcome gust and wind shear effects during low approach and to develop and experimentally investigate information display concepts, autopilot and flight director system coupling techniques and piloting procedures for all types and classes of Air Force aircraft ranging from utility or Forward Area Controller type vehicles to heavy C-5A transports and including helicopters, STOL high performance fighters, etc. The application of techniques that yield precise flight path control and reduce touchdown dispersion, provides for the military increased operational capability by being able to take advantage of the protection given by fog, cloud cover, or darkness during a tactical maneuver as well as providing for accident reduction, improved resupply efficiency, troop drop precision, more effective weapons delivery and increased aircraft utilization. Specific current efforts include the investigation of the use of a forward looking radar as an independent landing monitor, experiments in flight crew/autopilot workload sharing during IFR landing, flight investigation of the availability and usefulness of visual cues in actual zero - zero weather, and the demonstration of manual/automatic approach and landing capability for helicopter, STOL and VTOL aircraft. Future technology

efforts by the Air Force will include the investigation of new flight path control and flight director system concepts, the analysis and flight testing of four-dimensional path control techniques and the use of inertial techniques to supply radio guidance smoothing and augmentation and simulation and flight analysis of numerous display concepts and piloting techniques for low visibility operations.

The Air Force system development activity in the all-weather landing area is a critical part of a joint DoT/DoD/NASA National Microwave Landing System (MLS) Program. The effort is described in the National Microwave Landing System Plan dated July 1971 and involves five years of development activity beginning late in 1971 to provide a Microwave Landing System that meets the wide range of user operational requirements set down by the Radio Technical Commission for Aeronautics, Special Committee 117.

b. Navy

The Navy has been involved in an extensive research and development program to provide an in-flight monitor for its Automatic Carrier Landing System. The system, known as the AN/SPN-41, will also serve as a backup for Category II landing operations. The AN/SPN-41 is a microwave scanning beam system essentially compatible with the Army A-SCAN system. Because of operational pressures and the corresponding need for a transportable system, the Marine Corps plans to deploy an interim system that will be compatible with the airborne hardware being installed in high performance fixed wing Navy aircraft.

c. Army

The Army research and development program currently provides landing guidance systems for helicopters. The A-SCAN system evaluated to date, utilizes a scanning beam with extremely broad coverage providing for simultaneous multiple approach paths. The system also includes a Distance Measuring Equipment (DME) function. The Army forecasts that production quantities for use by operational forces will be introduced by 1976.

d. FAA

The FAA is expanding the implementation of current VHF/UHF Instrument Landing System (ILS). Their plan calls for installing conventional Category I, II and IIIA ILS through 1976 and the procurement and installation of Microwave Landing System (MLS) beginning in 1977. The FAA is also developing a precision IFR (Instrument Flight Rules) capability for STOL vehicles and to this end have procured test models of new development Modular Instrument Landing

System (MODILS) designed to meet FAA accepted operational requirements. The FAA considers STOL systems to be interim devices and intends to limit their deployment to promote early implementation of the new MLS.

e. DoT

The Department of Transportation's Transportation Systems Center is presently developing phased array antenna technology, studying landing guidance data rate requirements and performing analyses of systems that will satisfy combined requirements of Air Traffic Control, the National Air Space System and the Microwave Landing System.

(2) Commercial

a. DoD-Sponsored IR&D

Department of Defense-sponsored IR&D is being accomplished by the industry in the all-weather landing system area. These efforts generally involve studies and analyses consistent with the concepts and plans of the National Microwave Landing System Program.

C-2. Autopilot and Automatic Flight Control

(1) Government

a. Air Force

The Air Force has a major development underway in Survivable Flight Control Systems emphasizing the attributes of quad-redundant fly-by-wire techniques. Highly responsive and ultra-safe controls will result. Fully man-rated components and criteria for applying them to new aircraft will enhance the technology transition. Control laws for the large transports operating in low altitude mission modes in wake and natural turbulence will be demonstrated in a C-141 transport. Digital flight controls providing multi-mode optimization for tactical fighter mission modes are being developed. Each program will provide direct contribution to commercial transport flight control technology. Automatic terminal area navigation control schemes which include four-dimensional (x,y,z and time) coordinates will be developed for both transport and helicopter capability.

b. Navy

Navy flight control developments include studies for digital flight controls for high performance fighters, auto-throttle

investigations for carrier landings and specialized automatic control modes for anti-submarine tracking tasks with both conventional aircraft and helicopters. Carrier V/STOL flight tests will provide important flight control information relating to practical operational use of V/STOL aircraft and potential use of vectored thrust for in-flight maneuvering.

c. Army

Flight control developments are primarily involved with helicopter applications. Hydrofluidic augmentation schemes using computational techniques demonstrate highly reliable characteristics in the severe helicopter environment. More advanced blade control techniques such as boundary layer suction and blowing and pure jet flaps will be investigated. Means for reducing vibration modes induced by the rotor/blade combination will be explored from the active control standpoint.

d. NASA

In order to foster the application of advanced flight controls to civil aviation, NASA initiated a Digital Fly-by-Wire Flight Control Program in late 1970 and has more recently initiated an Active Controls Technology Program to provide design criteria and integrated design approaches to permit early application of active control concepts to air transports. STOL transport flight controls will be explored in the Buffalo augmenter wing and STOL-LAND automatic terminal area navigation flight test programs. Flight control development will also play an important role in the two experimental quiet STOL transports to be built for NASA in the near future. Major developments will be undertaken in support of the Space Shuttle automatic and manual controls. The Space Shuttle will be an unstable vehicle in most flight regimes and will have full dependence upon the augmentation system. Fly-by-wire is anticipated to be the mechanization technique employed.

e. DoT

Boeing is completing development and ground-based testing of critical supersonic transport flight control electronics and servo-actuator designs under a Department of Transportation contract.

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(2) Commercial

a. DoD-Sponsored IR&D

Boeing is conducting flight control developments for STOL transports, digital flight controls, and controls applicable to supercritical wing aircraft such as the Advanced Technology Transport. Honeywell has had a number of digital control studies underway. General Electric is heavily involved with flight control/weapon delivery related problems. Sperry has been investigating Space Shuttle controls and controls for other lifting body landing programs such as the X-24 and M2F2.

C-3. Load Alleviation and Mode Suppression

(1) Government

a. Air Force

The most significant Air Force technology effort in this area is the Control Configured Vehicles (CCV) Advanced Development Program. This pioneering program will develop and flight test validate automatic flight control technology which can significantly enhance military mission effectiveness of future aircraft. To this end, the program is divided into two major task areas, one developing control functions appropriate for the large flexible class of aircraft and the other aimed at the highly maneuverable (fighter) class of aircraft.

Under the large airplane task, the specific control functions to be developed include augmented stability for an aerodynamically unstable aircraft, flutter control, ride control, and maneuver load control. It investigates the compatibility and interaction of these functions. The last three are specific extensions of load alleviation and mode suppression control technology. Flutter control is the extension of LAMS technology to the control of potentially unstable structural motions. The CCV Program will provide the first flight test experience with such systems in late 1973. Other activity in this area is discussed in D-1, Page 158. The payoff of this technology will be extension of flutter speed limits without significant weight penalties.

The ride control development under CCV will provide the first flight experience with a ride system using dedicated miniature control surfaces and will provide the technology base necessary to integrate such capability into other systems performing other

structural response control functions. The function of such systems is to minimize the contribution of the flexible mode oscillations to the crew acceleration environment. The CCV ride system tests are scheduled for late 1972.

Maneuver load control is the use of control surfaces to provide direct lift control (positive and negative), during maneuver, on various parts of the wing to minimize bending moments created by the maneuvering. Analysis has shown that 10 to 20 percent reduction is achievable. This capability will allow significant reductions in wing structural weight for the same payload capability. The maneuver load control tests will be completed by late 1973.

Once the capability to perform such structural response control functions is validated through flight test and the technology is incorporated into the initial configuration development of future aircraft, significant weight and cost savings will result. Current projections indicate the potential of a 15 to 25 percent savings in weight of future bomber and cargo aircraft.

No approved flight test demonstration programs for conventional aircraft are known to exist under the Navy, Army, NASA and FAA in the above active control areas. The Space Shuttle Program could benefit considerably by the significant Air Force contributions.

SECTION III-D
VEHICLE DYNAMICS

Programs are detailed for the four significant advances in Vehicle Dynamics: (1) Vibration Reduction; (2) Flutter Prevention; (3) Airplane Acoustics; and (4) Sonic Fatigue.

D-1. Vibration Reduction

(1) Government

a. Air Force

Programs are directed toward engineering applications of the statistical energy analysis method. Also, methods to control airplane vibration from distributed sources of excitation such as noise and boundary layer turbulence will be investigated. In addition, studies are underway to develop design requirements and new dynamic analysis methods for advanced rotor powered VTOL concepts.

b. Navy

Considerable effort is being expended to improve the understanding of airloads, including vibratory loads, and other important parameters involving fatigue life, reliability and survivability of aircraft and helicopters.

c. Army

Comprehensive programs to develop new rotor concepts and rotor vibration isolation systems are being conducted for conventional helicopters and other advanced VTOL aircraft. A goal is to provide a 90 percent reduction in vibratory forces which are transmitted to the fuselage and passengers.

d. NASA

NASA has completed five studies in the 1969 - 1972 time period involving the statistical energy analysis method. They plan to continue this work and apply the results in Space Shuttle development programs.

(2) Commercial

a. DoD-Sponsored IR&D

Programs of practically all major airframe companies are to improve classical vibration prediction methods using modern high speed computers. Due to frequency limitations when using classical methods, companies such as Lockheed and Ling Temco Vought have included statistical energy analysis methods in their current programs.

b. Company Funded

Boeing work is to advance prediction of boundary layer turbulence and fuselage vibration for transport aircraft.

Lockheed work is to refine semi-empirical vibration prediction methods for transport aircraft using data from the C-141 and C-5 airplanes.

D-2. Flutter Prevention

(1) Government

a. Air Force

Active flutter suppression technology is being developed for application to aircraft where flutter critical components may be the wing, empennage, or wing with external stores. Efforts are directed at flight demonstration of active flutter suppression by 1973 on a B-52 airplane and 1975 on fighter aircraft with stores. Work is currently underway to develop engineering techniques for the optimization of aircraft structures subject to constraints both on flutter and strength to achieve minimum weight. This optimization method should be developed by 1974 and will apply to any flutter-critical aircraft component. Developments of unsteady aerodynamic methods, required for the accurate prediction of flutter instabilities, are underway and include interference effects between wing and tail for subsonic and supersonic flow and between wing-pylon-store for subsonic flow. By 1974 - 1975, further improvement and verification by acquisition of correlative test data should be accomplished. The application of advanced filamentary composites provides the capability for tailoring the structure, thus obtaining minimum weight designs subject to multi-disciplined requirements, viz., static and dynamic loads, fatigue and flutter. Prediction methods for the dynamic characteristics of composites are being developed and verified for flutter safety evaluations for a wide variety of specimens including representative complex aircraft structures. Initial developments will be completed by 1973.

b. Navy

The Navy is presently conducting research on advanced analytical methods for determining actual dynamic characteristics of air vehicles by including optimized corrections based on measured data. The development, validation, and application of advanced flutter analysis techniques are also currently underway and extends through 1975.

c. Army

The Army's principal concern in the aeroelastic area is prevention of flutter instabilities on helicopter rotors.

d. NASA

Feasibility of an active flutter suppression system having both leading and trailing edge control surfaces on a cantilever delta wing model to be tested in a transonic wind tunnel is being studied. Work is underway for development of an unsteady aerodynamic prediction method for control surfaces. Research is being initiated to explore possible methods for the critical and difficult transonic speed regime, where an unsteady aerodynamic method is lacking. Research in advanced composites includes the prediction

of dynamic characteristics of beams and plates and preliminary investigation of reinforcement of strength designs for flutter prevention. An exploratory flutter optimization program limited to supersonic speeds has been developed with plans for an overall Integrated Procedure for Aircraft Design (IPAD) including aerodynamics, controls, structure and propulsion. Other research which may have application to civil aviation include vibration analysis and modal coupling of very large vehicles, interference flutter of closely spaced aerodynamic surfaces, and panel flutter.

(2) Commercial

a. DoD-Sponsored IR&D

DoD-sponsored IR&D work with industry in the area of flutter prevention applicable to both military and commercial transport aviation includes unsteady aerodynamics for transonic, mixed flow by General Dynamics: flutter optimization using beam theory and a minimum strain energy approach by North American; more rapid flight flutter testing techniques by McDonnell Aircraft; and unsteady aerodynamics for wing-body configurations and cowls on large fanjet engines by Boeing.

D-3. Airplane Acoustics

(1) Government

a. Air Force

A program is being conducted on a novel jet propulsion concept which utilized numerous micro-jet exhausts to reduce aural detection*. Efforts also include the definition, simulation, and reduction of the near field noise environment arising from high lift devices for military STOL airplanes.

b. Navy

Noise research programs are directed primarily toward quieting surveillance aircraft. Current work includes evaluating the "Wankel" type internal combustion engine. In addition, the Navy continues effort to understand and control engine-generated noise, including the evaluation of engine ground run-up suppressor concepts.

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*See Appendix 1, Section III-D.

c. Army

Research is almost exclusively related to rotary wing vehicle noise to minimize detection distance. Programs include basic studies of rotor noise generation and propagation as well as wind tunnel investigations. The Army is participating in the ARPA sponsored Quiet Helicopter Program.

d. NASA

An extensive program in Noise Abatement is underway which includes investigation of all engine noise sources in terms of generation, propagation, subjective reaction, and suppression. These investigations range from basic research studies of noise generation from jets and rotating devices to full-scale demonstration of quiet engines. NASA is currently developing an Aircraft Noise Reduction Laboratory which is expected to be in operation in 1973. In addition, NASA programs define the aero-acoustic structural loads of the space transportation system from the propulsion system and from flight in the atmosphere during exit and reentry. NASA is also participating in the ARPA sponsored Quiet Helicopter Program.

e. DoT

Concern is primarily with aircraft noise from the standpoint of regulating actions on community noise. Efforts include jet and coaxial flow jet studies, V/STOL noise studies, fan and compressor noise prediction and reduction programs, noise propagation studies and a subjective evaluation of STOL noise. Future efforts include exhaust noise suppressor research, engine cycle modifications for noise reduction and jet and turbulence structure investigations.

(2) Commercial

a. DoD-Sponsored IR&D

Extensive efforts include Quiet Nacelle Developments by Boeing and McDonnell-Douglas and the Quiet Engine Program at General Electric. United Aircraft investigates noise generation and noise reduction concepts.

D-4. Sonic Fatigue

(1) Government

a. Air Force

Narrow band random fatigue information for various materials and structural joint configurations is being developed for incorporation into design methods. Efforts are directed to the generation and improvement of design methods in the form of nomographs which can be employed by design engineers in early stages of the military aircraft design. Work is underway to determine the effects of elevated temperatures on the sonic fatigue of structures which are located in or near the engine efflux and should result by 1974 in design information for structures which are exposed to a combined environment of high intensity noise and temperatures up to 800°F. This work will be extended to include the temperature range up to 1200°F. The investigation of random fatigue properties of advanced filamentary composite materials will continue. Experimental test methods and techniques are being developed and improved so that reliable simulation of the combined environment can be performed for design verification and qualification purposes. Planned efforts will further refine sonic fatigue design methods by the inclusion of multiple modes and dynamic non-linearities.

b. Navy

Effort is mainly directed toward the development and improvement of structural response prediction of vibrations which are excited by acoustic noise or turbulent flow pressure fluctuations.

c. Army

No work on sonic fatigue appears to be in progress or planned, although there is work on fatigue and fracture mechanics at the Army Materials and Mechanics Research Center, Watertown, Massachusetts.

d. NASA

Work is underway to determine the sonic fatigue resistivity of the Space Shuttle thermal protection system (TPS). Attempts are being made to improve simulation of the heat distribution existing on the TPS during reentry. Material fatigue data are being obtained for stainless steel fibermetals which are employed in sound absorbing structures. Research into the structural response excited by convected turbulence in supersonic flow is being conducted. Wind tunnel experiments to verify the theory are in progress. A study of the effects of

various design details on the stress response resulting from acoustic excitation is being conducted.

(2) Commercial

a. DoD-Sponsored IR&D

DoD-sponsored IR&D work with industry in the area of sonic fatigue prevention is mainly concentrating on the prediction of dynamic stress response which result from acoustic and turbulent flow excitation. Limited work to investigate sonic fatigue in combined thermal-sonic environment is planned by Northrop. The effects of weld-and-rivet bonding on the sonic fatigue resistivity will be investigated by Ling-Temco-Vought.

SECTION III-E
VEHICLE EQUIPMENT

R&D programs of benefit to civil aviation are detailed for the three significant advances in Vehicle Equipment Technology: (1) Landing Gear, (2) De-icing - Anti-icing, and (3) Pressurized Aircraft.

E-1. Landing Gear

(1) Government

a. Air Force

Presently under development is a revolutionary new landing gear which replaces the conventional wheels, tire and brakes with a cushion of air which is maintained beneath the fuselage. This air cushion system allows the aircraft to land and take-off from grass, snow, soft soil and lakes as well as conventional runways. The system was originally developed and flight tested on a small 2500 pound aircraft under Air Force contract. At present, the system is being installed and tested on a deHaviland "Buffalo" aircraft. This aircraft can be used for either cargo or passengers, and it has both military and civil applications. It should be particularly attractive for use in underdeveloped countries because it does not require runways for operation. The Canadians plan to use it in the Arctic because it can operate from the snow in the winter and will not disturb the delicate vegetation which exists in the summer. The initial development and flight test program for the Air Cushion Landing System is being funded jointly by the Air Force and the Canadian Government on an equal basis.

Also under development is a new aircraft tire which will allow the tire to be retreaded without removing it from the aircraft. This replaceable tread tire has already been tested on a small (3000 pound) aircraft and is now in development for the C-130 size aircraft. It has been estimated by the AFLC that savings in logistics and maintenance would be in the order of $1,000,000 per year for the C-130 fleet. When applied to commercial aircraft and possibly even automobiles, large savings in maintenance and operating costs will result. This effort is the only known development of replaceable tread tires.

b. Navy

Study efforts have been funded by ARPA and managed by the Navy on the possible use of air cushion landing systems in carrier-based aircraft.

c. NASA

NASA has worked on landing gear related problems over an extended period of time. Particular attention has been paid to landing loads, tire-friction/skidding, braking, and cross-wind design.

(2) Commercial

a. DoD-Sponsored IR&D

There are a number of landing gear programs with the major aircraft manufacturers. The objectives of these study efforts are as follows: (a) landing gear systems research focused on the development of an efficient brake system, and (b) continuing efforts on an analysis of brake hydraulics, tire dynamics and improvement on brake control simulation. Within these efforts are tasks to improve all-weather brake performance, alleviate landing loads and improve ride comfort during taxi, reduce tire wear and system maintenance and eliminate chronic brake vibration problems. Other work effort is primarily on shock strut dynamics, steering and ground handling, brake dynamics, and brake control.

E-2. De-icing and Anti-icing

(1) Government

Government discussions are presently taking place which are expected to lead to a joint USAF and NASA R&D effort in the area

of airframe ice accretion prediction (See Ref. 23, Page 103). The objective of this effort is to provide techniques to enable the aircraft designer to predict ice protection system requirements during the aircraft design. This will provide both civil and military designers the capability of avoiding changes resulting from icing flight tests. Army efforts are addressing the operational effectiveness of rotor craft to fly in icing conditions. The program includes identification of problems encountered, concepts for alleviation, and establishment of concept feasibility.

The presently on-going icing simulation with tanker aircraft will continue to be available for both military and civilian aircraft. Partial evaluation of the Lockheed 1011 and the Concorde late this year are in the planning process.

E-3. Pressurized Aircraft

(1) <u>Government</u>

a. Air Force

The transition from unpressurized to pressurized compartments involve major environmental control developments in heat removal equipments, air cycle machinery, pressure control devices, and heat exchangers.

The emergence of new avionic solid-state devices requiring cryogenic temperatures to achieve their performance objectives set the stage for the new requirements in the environmental control area. Requirements and capabilities in the cryogenic temperature range were surveyed (1963), and a program to develop lightweight cryogenic coolers was undertaken. While space cabin air regeneration techniques had only been explored briefly (1959 - 1964), the idea of generating oxygen for aircrew members while in flight quickly gained acceptance in concept. This has resulted in several joint Air Force/Navy developments, as well as a current program to satisfy B-1 aircraft needs.

Aircraft thermal control systems were studied and revealed the fact that their environmental control systems were designed from consideration of one or two "worst condition" points, and their selection was primarily governed by a compromise between least initial cost and unconfirmed ideas about what pilots and sensitive equipments could stand. The studies of maintenance records revealed an exhorbitantly high number of avionic failures which have been attributed primarily to inadequate design of the environmental control system.

Techniques for analyzing heat loads of "black boxes" have continued to establish design methods for handling these loads Exploratory programs to achieve cryogenic temperatures, using novel concepts such as thermal compression, Vuilleumier cooler, micro-miniature turbine coolers and rotary reciprocating coolers, demonstrated feasibility in the 1964 - 1967 period. Advanced development programs are still underway and are now beginning to demonstrate significantly better performance and reliability. Secondly, an analytical program for environmental control systems is underway which will consider total mission performance. The program, which is nearing completion, will give designers a capability to determine performance, physical characteristics, system penalties, and costs in such a manner that rational comparisons and selections can be made from various environmental control system configurations.

An advanced development program has been authorized to verify these capabilities by flying an advanced environmental control system in a test aircraft. The system will provide stable and suitable environmental conditions throughout the military mission by employing both new devices and new system arrangement. Among innovations will be a separately driven compressor to fill voids in bleed air capacity of high performance jet and turbojet engines, high pressure separation of water to eliminate freezing, drenching and pulsing of systems, heat load sensitive controls to assure minimal range penalties to the vehicle, higher temperature, lighter heat exchangers using titanium and fluidic controls. The spinoff from this program should not only improve total weapon system performance and save millions of dollars annually in reduced avionic failures, but should also form useful techniques for subsonic and supersonic commercial airplanes.

The advances in cryogenic coolers and on-board oxygen generators like other subsystem developments have occurred without corresponding activity in the civil area. When their requirements do arise, the technological base will be available. Recent requests for consultation on coolers for weather mapping, clear air turbulence detection, geological and agricultural surveys, oxygen generators for hospitals, emergency solid oxygen for transports, and use of environmental control system analytical programs may indeed be indicators of coming technology transfers to civil markets.

b. Navy

The Navy has been exploring the effectiveness of thermal control systems as it relates to electronic components and is planning to further define the importance of stable temperature conditions on avionic components by a thorough program to establish failure rate

data from cyclic temperature variations. As mentioned, joint Air Force/Navy programs are developing self-contained oxygen systems for high performance military aircraft.

c. Army

The Army has not been active in this area of technology. Aircraft utilized by this service fly low level (altitude) troop support missions thereby precluding any generalized requirement for pressurized cabins.

d. and e. NASA and FAA

Neither NASA nor the FAA have developed programs in the aeronautical area of environmental control. The supersonic transport program depended almost exclusively on prior developments related to military aircraft. Many of the problems which they may encounter should be solved in current military development programs, and the possibility of covering the remainder would exist if this program were expanded. R&D funding limitations prevent such an expansion, however.

(2) Commercial

a. DoD-Sponsored IR&D

The DoD has supported a low level of IR&D effort among component manufacturers such as AiResearch Division of Garrett Corporation and Hamilton Standard Division of United Aircraft. Examples are development of low-cost cabin pressure regulators and conditioning concepts applicable to private or military aircraft. More recently, both component and aircraft companies have undertaken efforts to investigate the use of heat pipes as one solution to avionic component heat rejection problems. Their motivation has been more along the line of how to use this new device rather than explore and expand its working principles. Within the past year, at least four companies have undertaken IR&D programs to develop transient control analyses which would be applicable to environmental control systems.

b. Company Funded

Company funds have been used by AiResearch to develop and test on airliners air cycle coolers which run on air bearings. The company is attempting to prove that although the initial cost of such a cooler may be higher, its longer life and lower overhaul costs make it a more attractive system for airline and military alike. There are also some efforts underway to develop fluidic elements for environmental control systems.

SECTION III-F
AIRCRAFT DEVELOPMENTS

Programs are detailed in this Section for four significant advances in Aircraft Developments: (1) STOL Aircraft, (2) Helicopter, (3) VTOL-V/STOL Aircraft, and (4) Cargo Aircraft - Cargo Handling.

F-1. STOL Aircraft

(') Government

a. Air Force

The Air Force has initiated the development of an Advanced Medium STOL Transport (AMST). The objectives of this prototype program are to: (1) design, fabricate, and evaluate a prototype aircraft which will demonstrate in hardware new technology, which after additional engineering development, will provide a medium sized (C-130 class) jet STOL transport; (2) provide a low cost development option for modernization of the tactical airlift force; (3) obtain visibility on costs associated with short-field performance; and (4) define STOL operational rules, safety rules and related design criteria. The prototype will be designed to accommodate a 15-ton payload at an operating radius of 500 NM, and to operate from unimproved 2,000 feet airstrips. Data and experience from this program will be of value to civil development of STOL.

b NASA

NASA technology programs have progressed to the point where flight tests for proof of concept and more detailed flight programs to develop design and certification data as well as operational data related to STOL systems of interest to civil and military applications and critical to decisions related to design and development of operational systems are warranted. The first turbojet powered augmentor-wing lift system (on a modified C-8 aircraft in a joint program with the Canadians) was initially flown in March 1972. In addition, turbojet-powered-lift quiet experimental STOL research airplanes (QUESTOL) are under study by three contractor teams. A single contractor will be selected to finalize and build two research aircraft in September 1972. These aircraft will fly in late 1974 and early 1975, according to current plans. It is intended to provide these aircraft with externally-blown flaps, and also provide the capability to change powered-lift concepts. The research aircraft will have the following nominal characteristics:

450

Weight - 50,000 - 70,000 lbs.
Wing loading - 55 - 90 psf.
Thrust/weight - 0.4 - 0.7.
Sideline noise <95 EPNdB/500'.
Speed = 0.8M design; 0.5M for testing.
Stability and control augmentation.
X-wind gear lift.
Direct control.
Speed modulation.
Landing and take-off from ∿ 2,000 ft. runway.

(2) Commercial

a. DoD-Sponsored IR&D

Industry related efforts in STOL technology are being conducted by virtually all potential transport manufacturers.

F-2. Helicopter

(1) Government

a. Air Force

Current effort is in the area of variable diameter rotors. This is of interest because of its wide ranging application to more efficient, higher speed compound helicopters, tilt rotor and stoppable rotor aircraft as well as crew escape and recovery system.

b. Navy

Two advanced rotor system concepts are being investigated that are aimed at improving the speed capability and aerodynamic efficiency. One concept is Fairchild-Hiller's "Reverse Velocity Rotor" (RVR). This uses higher harmonic feathering of the rotor blades and airfoil shapes which permit lift to be generated on the retreating blade at high advance ratios (e.g., >1.0). Conventional rotors reach a limit where the retreating blade stalls. This is eliminated by the RVR concept. The second concept is being developed by Lockheed and has objectives similar to the RVR's, that is, high advance ratio flight. This rotor system uses programmed leading and trailing edge blowing of an airfoil which is symmetrical about its mid-chord. Other objectives of the blown airfoil rotor are: structural and mechanical simplification by elimination of all blade hinges, including the feathering hinge; use of thicker, more rigid and lighter blades while still retaining good aerodynamic efficiency;

and the solution to the stop-start problem of horizontal plane stoppable-stowable rotor (controlling of the pitching and rolling moments).

The Navy was planning the development of a heavy lift helicopter with a 12-ton payload capability as a growth version of the CH-53D. It would have been the CH-53E, however, necessary funds have been deleted by Congress. Navy support for an advanced rotor system for the CH-53D is still active; this rotor development will be important to, and support the Navy heavy lift helicopter program should it be funded at a later date. The advanced CH-53D rotor involves the development, fabrication, and testing of titanium hubs equipped with elastomeric bearings, titanium spar fiberglass shell blades, and changes in twist, taper and tip shape to improve performance and reduce rotor noise.

c. Army

An extensive effort is aimed at developing advanced rotor concepts and rotor craft. Primary among these are:

1. Variable Diameter Rotor (Sikorsky Telescoping Rotor Aircraft).

2. Advancing Blade Concept Helicopter (Sikorsky ABC).

3. Controllable Twist Rotor (Kaman CTR).

The Army is procuring an experimental prototype of a helicopter based on the ABC concept. This system uses highly rigid, propeller-like rotors in a coaxial, counter-rotating arrangement. The blades, hub and rotor mast systems are simple and ruggedly built. Collective and cyclic feathering are used for control, and at high forward speeds the rotor blades are feathered so that only the advancing blades carry lift; the retreating blades are unloaded. Because of the coaxial system, the lateral moments produced by each rotor on the aircraft are balanced out. Thus, high advance ratios can be used, retreating blade stall limits eliminated, and increased lift and maneuverability produced with increasing speed. High speeds are possible (e.g., 350K) with auxiliary propulsion in addition to improved rotor aerodynamic efficiencies and lower vibration. Primary interest is in the potential of a rugged helicopter with high invulnerability to battle damage. Some of the developments coming from the ABC rotor already are being introduced by Sikorsky into production helicopters for example, the titanium spar blades for the Navy CH-53D helicopter.

The Controllable Twist Rotor is based upon the control of the rotor blade incidence through the use of a trailing aerodynamic control surface mounted near the tip of the blade. In the CTR system cyclic and collective control are applied both at the blade root and near the tip in a programmed manner. Thus, the blade twist can be varied both collectively and in azimuth position to produce better hover efficiency, higher speed, more efficient cruise flight and lower blade stresses.

The Army is presently engaged in full-scale component development for a heavy lift helicopter with a payload of 26 to 28 tons with Boeing-Vertol as contractor. The development of new components for these helicopters such as titanium hubs, composite blades, elastomeric bearings, and combiner transmissions will lead to safer helicopters with greatly reduced maintenance. These reduced maintenance (and operating) costs will make the utilization of large commercial helicopters profitable, and will have an important effect on civil VTOL aviation in areas of transport, construction, and other related functions.

d. NASA

Helicopter development is being supported by flight and wind tunnel testing. Recent wind tunnel testing has been for such efforts as the Sikorsky ABC rotor and Vought Helicopters' Dorand Rotor.

(2) Commercial - IR&D and Company Funded

The various helicopter companies all have programs aimed at improving their design, development and manufacturing capabilities. In general, they are engaged in the following efforts:

Design and evaluation of new or advanced concepts of rotor craft; examples: Sikorsky's ABC rotor, variable diameter rotor, S-67 winged attack helicopter; Bell's variable diameter rotor, flex hub rotor.

Product improvement programs which involve numerous components of helicopters. Examples: Sikorsky's titanium spar blade, elastomeric hub, canted tail rotor, three turbine transmission; Vertol's winged helicopter modification, improved transmissions capable of dry operation for limited time, fiberglass rotor blades; Bell's quieter rotor blades, and development of an improved tail rotor system.

Design studies in preparation for entering competition for military aircraft. Examples: design studies done for the heavy lift helicopter by Hughes Tool, Sikorsky and Vertol; design studies for the Army's Utility Tactical Transport Advanced Aircraft System (UTTAAS) program; design studies for the Navy's Light Attack Multi-Purpose System (LAMPS) program.

Vertol as well as Sikorsky and Hughes Tool, have invested heavily in design study, analysis and model testing as prelude to the contract award. Both company and IR&D money were involved.

F-3. VTOL-V/STOL

(1) Government

a. Air Force

The Air Force is participating with the Navy, Army, and the FAA in a downwash investigation program that is designed to develop an instrumentation capability for downwash measurements and includes evaluation of instrumentation types and location of the instrumentation in the vertical and horizontal planes. The program is designed to determine the downwash and horizontal flow effects on personnel, material and on the environment in which the operation is being conducted. Among the factors to be evaluated are disc loading, gross weight, the number of blades per rotor, and single versus tandem rotors. The proposed program will provide a downwash data base for the understanding of downwash cause and effect a development of operational techniques to minimize the effects and data on which future design studies can be based. It is proposed that all future aircraft having VTOL or V/STOL capabilities would be required to include a downwash test in the prototype flight test program. The proposed program will be applicable to both military and civil aviation, and will be especially meaningful for establishing civil aviation requirements which presently do not exist. Advancements in future crane helicopters and passenger carrying prop-rotor aircraft for city-center to airport or to another city-center will require this knowledge.

VTOL Integrated Flight Control System: This program (1966 - 1970) was a systematic investigation, analysis, and integration of the interrelated disciplines involved in VTOL Flight Control System Technology. The purpose was to develop, validate, and demonstrate flight control system technology including handling qualities criteria, criteria for flightworthy control system hardware,

definition of control-display design criteria (IFR and VFR), and flight reference data sensors and computing element requirements. Results of this program consist of a Preliminary Military Specification for VTOL Aircraft Handling Qualities, design requirements for VTOL flight control systems, and control-display requirements for VTOL aircraft. This program was terminated due to loss of the variable stability VTOL test aircraft prior to validation and demonstration of the criteria and control system technology developed. The technology developed is directly related to civil V/STOL aircraft.

Propeller Technology: An Air Force-sponsored cyclic pitch propeller development program (1969 - 1972) was initiated to develop the technology base for propeller-driven tilt wing aircraft. The objectives were to develop an understanding of the propeller design parameters and their effect on static thrust; to determine the amount of pitching moment that can be obtained from cyclic pitch inputs on a propeller; the effect of advanced materials on the weight and performance of the propeller; the integrated design of the propeller and gear box; and the development of manufacturing and testing techniques for large (25 foot) diameter propellers which have been designed to use advanced materials such as titanium and borsic aluminum. The tilt-wing V/STOL concept is applicable to civil uses as a short to intermediate range transport aircraft, and the technology base that was developed during this program is fully beneficial to both requirements.

Prop-rotor Technology: Efforts have been conducted that range from application studies, preliminary design and wind tunnel tests through a detailed theoretical prediction techniques development for performance, dynamics and stability and control. The prop-rotor concept shows exceptional promise for the military roles of: an advanced rescue aircraft, a light utility aircraft, or a medium gross weight transport. Because of the low noise and low velocity downwash characteristics, the prop-rotor configuration is directly applicable to civilian operations. These include: city-center to city-center, or city-center to airport operations; Coast Guard rescue missions; intermediate range commercial transports; and civil utility operations. The Air Force is presently participating with the Army and NASA on two prop-rotor technology programs: (a) development and test of a 25 foot folded prop-rotor and a 26 foot tilt-rotor, and (b) development and test of a folding prop-rotor force model.

b. Navy

The Navy is participating with the Air Force, Army, and FAA in the downwash investigation program.

In the integrated flight control area they have entered a joint program with the Royal Air Force (United Kingdom) and the Royal Canadian Air Force for a terminal area flight test of the CX-84 at Patuxent River, Maryland, for one year beginning in February 1972. Related Navy efforts consist of in-flight evaluations and validation of handling qualities requirements using the variable stability X-22A V/STOL vehicle. The Air Force, NASA, and FAA are participants in this on-going Navy program.

Because of the new concept of Air Capable Ships (ACS), the Navy is strongly engaged in the development of advanced V/STOL fighter aircraft and V/STOL support aircraft. Currently, a quantity of Harrier aircraft (AV-8A) have been procured for Marine operational evaluation in connection with the ACS program.

c. Army

The Army is participating with the Air Force and FAA in the downwash investigation program. They are heavily involved in development effort on prop-rotor and are participating with the Air Force and NASA on these programs A major effort to demonstrate tilt rotor technology is a current Army-NASA program to design and fabricate two research aircraft.

d. NASA

NASA is providing wind tunnel testing for the military services and industry on various V/STOL efforts.

NASA is participating with the Army and Air Force in the development of prop-rotor technology. NASA is involved in a program to detail a development plan for follow-on procurement of two flight research aircraft. NASA also is actively using the Ryan XV-5B fan-in-wing aircraft in a flight test program.

In the remotely driven lift-fan area, NASA is pursuing design studies for lift-fan transports with three contractors, and design and development work for quiet lift-fan systems with two engine companies. These efforts are basically aimed at the jet propelled V/STOL transport area.

Efforts to improve knowledge in the integrated flight control area also continue. The X-14A (jet-lift) aircraft still is being flown in furtherance of this technology expansion.

(2) Commercial - DoD IR&D and Company Funded

The areas in which these efforts are being pursued are:

V/STOL Propeller - Both Hamilton-Standard and Boeing-Vertol efforts involve analysis, structural development, and testing. Another company has begun investigation of the supersonic propeller as a means for developing superior military aircraft.

Prop-rotor - Bell Helicopter and Grumman Aircraft are both continuing efforts to develop aircraft using this V/STOL propulsion approach.

Lift-Fan - General Electric is continuing research and development of lightweight, quiet, remotely-driven lift-fan systems. Lycoming is engaged in integral lift-fan developments.

Other propulsive concepts also are being investigated such as augmented thrust by Bell Aerosystems and North American and stoppable rotor by Sikorsky, Boeing-Vertol, Bell and Lockheed.

F-4. Cargo Aircraft - Cargo Handling

(1) Government

a. Air Force

Since the development of the Air Force Cargo Handling System (463L), there have been no large programs for an advanced system.

b. NASA

Studies are being made by Boeing, Lockheed, and General Dynamics on a high subsonic (M = 1.0) long range transport aircraft. The studies will determine the benefits of applying advanced aerodynamic technology to transport aircraft of the 1975 - 1985 time period.

In addition, NASA Lewis is funding companion studies with the propulsion industry.

While the studies are aimed at passenger transports, the results would be applicable to long range cargo airplanes for the Military Services.

(2) Commercial

a. DoD-Sponsored IR&D

Studies of advanced cargo systems are being undertaken by companies who have large jet aircraft. In one program, an analysis of pallet heading (manifest) cards for single 463L is being examined. Integrated with this is a study of development of cargo loading computer models. An additional effort is a preliminary design study of an automatic cargo loading system that would eliminate the requirements for rollers. This preliminary design approach is being directed toward commercial air freight.

In order that larger payloads for future wide jumbo jets can be made practical, new concepts in cargo handling are visualized. Future developments are conceived around the use of standardizing cargo containers. A reduction in the indirect cost associated with the handling of palletized and bulk cargo is regarded by the airlines as equal in importance to a reduction in direct operating cost. The investigations to improve cargo handling for large wide-bodied jets will have application to both commercial and military transportation in the future. These improvements of cargo handling systems are expected to make the approaches compatible with ground servicing equipment.

Another effort related to ground handling capabilities at airports and terminals is the development of a computer model for air cargo terminal analysis. Advanced study efforts are concerned with the configuration of heavy loads in commercial freight airplanes. One approach would be to load cargo in a uniform span-wise cargo loading configuration. For future use, this might evolve into an improved aircraft loading system for both military and commercial use.

SECTION IV
SUMMARY

From 1925 to 1936, the civilian sector of aviation, including the NACA, made more significant contributions to aviation progress than the Military Services. During this period, however, the military test pilots were both deeply interested and concerned about the flying qualities of airplanes and were making serious efforts to understand and resolve the many problems that they encountered in using their airplanes. By 1936, the Military Services were taking steps to improve aircraft design. By the end of World War II, a broad R&D expertise existed in the Army Air Corps and the Navy. During the 1950's, the military, working with the NACA particularly at their Langley and Ames Laboratories, contributed strongly to air vehicle technology. In the more recent 60's, military mission requirements provided an order of magnitude increase in the complexity of aircraft. Aircraft developments proceeded on a joint government-industry basis with military requirements providing the main driving force.

Military performance improvements in the tactical agility of fighter aircraft obtained through delay of buffet onset and drag rise, will provide technology for the advanced technology transport. The military contribution to the NASA supercritical airfoil program is financial but will permit full-scale demonstration in flight on a current F-111 test airplane. Existing military programs on compatibility of the jet engine with the air inlet, and improvement in the overall integration of the airplane and engine will not only resolve military performance problems, but also lead to more efficient airplane designs that will be of benefit to civil aviation.

The tremendous importance of structural weight in determining the payload fraction of airplanes has always dominated air vehicle design. Related as it is to initial cost and operational economy of aircraft, structures that are as light as possible must be developed, but the sobering effects of freedom from structural failures and aerodynamically induced structural instabilities such as flutter, of necessity monitored by the military, will result in continuing the flow of technology from the military to the civilian sector. Other associated programs, such as elimination of sonic fatigue failures and development of covert (quiet) airplane technology, involve noise suppression at the airplane (the so-called near field). The technology developed will assist in the abatement of noise in the far field, i.e., the airport community.

The jet age aircraft problems of flight control were first met and coped with by military engineering programs. Simple, case contained flight instruments of a few kinds were augmented by others and later replaced by whole instrument computer systems. Mach effects on aircraft produced variable and often inadequate stability and even control force reversals. The use of stability augmentation and powered controls were evolved during the 1950's to cope with these problems. Civilian transports were benefited by this technology when it was developed to an acceptable level of reliability and economy. Sophisticated military weapon systems of this same era required the development of the art and science of human engineering - the determination of the pilot's role and the provision of his displays and controls to effect it. It is currently observed that airline operators have achieved a full appreciation of the importance of the pilot-control-display field and that civil sponsored programs are in being and producing results valuable to military flying. It may be forecast that the 1970's will see a greatly expanded use of control technology in civil aviation. The control of STOL vehicles will certainly require the use of exotic aerodynamic controls and engine produced flows and forces harmonized by automatic controls. Control technology will be exploited, variously and appropriately, for more efficient cruise, improved ride, improved structural life, and greater precision of landing.

For the landing gear, the goal has always been one of reducing complexity and improving reliability. The major developments progressed from simple wheels on axles to wheels and brakes, mechanical and then hydraulic shock struts to retractable gears. The larger aircraft demanded larger wheels and higher tire pressures. Large aircraft such as the B-36 and XC-99 made their impact in landing gear design by showing the advantage of reducing from 110 inch diameter wheels to 56 inch dual tandem bogies. With further increase in aircraft speeds and the necessity for ground handling improvements, tricycle landing gear, nose wheel steering and anti-skid devices were developed. One of the most critical problems still in existence to some extent is nose wheel shimmy. A large dent in this problem was made by military R&D in developing the basic theory and analysis used throughout industry today in predicting and preventing the onset of shimmy. There are some developments on the near horizon which are significant for the military and offer direct conversion to civilian use. These are the Air Cushion Landing Gear System and Replaceable Tread Tire. The Air Cushion Landing Gear System can be used in a

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civil application for future STOL aircraft. The replaceable tread tire, when applied to commercial aircraft, can result in large savings in maintenance.

Cabin pressurization and anti-icing brought the physicists and thermodynamicist into airplane design and generated military programs in Environmental Control Systems. This almost exclusively military generated technology provides stable and suitable environmental conditions throughout the airplane, surprisingly, not only for crew and passengers, but also for the equipments of the modern airplane, both military and civil. The benefit of such work is that it can save millions of dollars annually in reduced avionic equipment malfunctions and failures and contribute to safe, effective flight.

Aircraft capable of operating into very small areas basically divide into two classes, V/STOL and STOL. V/STOL aircraft range from the helicopter to the high speed airplane. While of great importance to military mobility, these aircraft can provide good solutions to improving the efficiency and speed of city-center to city-center travel. Such commercial transport systems do not yet exist, but the technology base for this has been firmly established by military and NASA activities. In fields other than commercial transportation, the helicopter has found increasing use by municipalities, business, and industry. In commercial transportation, STOL airplanes offer a near term solution to relieving airport and airway congestion and significantly increasing the number of passenger movements. Both the military and NASA are strongly pursuing STOL development. The military contribution to development in the transport aircraft and cargo handling field has been overriding, providing the basis for practically all modern commercial transports and for the essential cargo handling systems.

In the Air Vehicle Technology, the apparent deviation of military R&D from concurrence with civil aviation needs may not exist because the technological base, from which problem solutions and new design questions must be answered, is a major concern of the Military Services.

APPENDIX 7

MILITARY RESEARCH AND TECHNOLOGY PROGRAM
RELEVANCY TO
CIVIL TRANSPORT AVIATION R&D NEEDS

JOINT DoD-NASA-DoT
"R&D CONTRIBUTIONS TO AVIATION PROGRESS"
(RADCAP) STUDY

CAPTAIN JERRY R. STOCKTON
USAF/AFSC (ASD/XR)
PANEL CHAIRMAN

AUGUST 1972

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SECTION I

INTRODUCTION

This appendix is a part of the Research and Development Contributions to Aviation Progress (RADCAP) Study, and is designed to identify the future research and development needs of civil transport aviation and the current or planned military (DoD) aeronautical technology programs which are relevant to those needs.

The following sections will not only identify the technical R&D needs of civil aviation, but also attempt to identify some of the non-technical factors. The non-technical factors have become in many instances, the driving force behind particular technical research and development needs. Although technical needs have been identified and separated in terms of environmental factors and system elements, it must be recognized that the solution, or lack thereof, of any one particular problem will have a direct impact upon the solution of many other problems. The most prominent example of this action can be seen in the possible solution to noise abatement. Each subdivision of research and development needs is intended to be a complete discussion on the subject and, in many cases, redundancy may exist between elements because of the interrelationship between the specific needs for two or more system elements.

Planned military (DoD) aeronautical research and technology programs that are identified as contributing to civil aviation R&D needs are those in which a high level of confidence for approval and funding exists. The research and development civil aviation needs have been extracted from the Joint DOT-NASA Civil Aviation Research and Development (CARD) Policy Study published in March 1971 and submitted to the Senate Committee on Aeronautical and Space Sciences and the House Committee on Science and Astronautics.

The first section of this appendix will cover the factors influencing the current priorities of civil aviation R&D needs. The organization of the following sections will identify: (1) agency responsibilities; (2) civil aviation R&D needs; and (3) military technology programs relevant to those needs.

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SECTION II

CURRENT CIVIL AVIATION R&D PRIORITIES

A brief review of the aeronautical advances and innovations from 1925 to 1970 reveals that military R&D had major effects on civil aviation. The historical priorities in aviation R&D have been those directly related to aircraft performance. Higher speeds, increased range, and increased aircraft size have resulted in the growth of civil aviation illustrated in Table 1:

ELEMENT	1945	1960	1970	1985(EST)
REVENUE PASSENGER MILES, BILLIONS	3.8	39	133	685
REVENUE TON-MILES, BILLIONS (CARGO)	0.1	1.3	5.9	67
GENERAL AVIATION AIRCRAFT, THOUSANDS	37	68	131	287
AIRPORTS	4,026	6,881	11,165	15,000

TABLE 1. GROWTH IN CIVIL AVIATION COMPONENTS (Source: DoT TST-10-4, pg 4-5)

The priorities of the aeronautical industry have been and are technically oriented. However, the emphasis on technical advances has been recently constrained by the increased emphasis on nontechnical institutional factors. The most prominent institutional factors are those based on social attitudes, finance, and politics.

Recent public concern with environmental problems has fostered widespread community demands for significant reduction in aircraft noise and air pollution. Airports are no longer afforded the sanctity of "open spaces" between themselves and residential communities. In certain cases airport operations have been restricted in response to demands for noise reduction.

The most important financial factor which is currently impacting the industry is the grave economic situation that is being experienced. In addition to a decline in U. S. Government purchases of aircraft and related equipment, the airlines have seen a steady decrease in profits over the past few years. This state of instability has forced both the aerospace and airline industries into a position where major problems must be faced.

Political factors are those born from legislation and regulation. One major problem is that the industry's entry into a particular market, and the price competition within that market are closely controlled.

Another influence on research and development priorities is the future pattern of civil aviation development. The historical development of civil aviation has been to create and improve on the basic element of aviation, namely, the vehicle and its directly related components. The other elements of civil aviation (airport, airways, and ground transportation) have then reacted to new demands placed upon them by the new vehicle. The recent growth of airlines and the technical advances which have given us bigger and faster vehicles have placed all other elements of civil aviation under a great deal of stress in order to catch up with air vehicles. Airport congestion and airline delays are two prime examples where the development of airports and airways have been unable to stay abreast of air vehicle development. This imbalance within the system will require that attempts be made to optimize the entire system.

All of the constraints and factors listed in the preceding paragraphs have played a role in developing the current priorities of civil aviation R&D needs. The CARD Policy Study has outlined the current priorities as noise abatement, congestion, high and low density short-haul, and other areas to include long-haul technology, air pollution, air cargo, general aviation, and continued broad based technology. In Section IV a detailed outline of specific R&D needs will be discussed.

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SECTION III

RESPONSIBLE AGENCIES

The government agencies responsible for aeronautical research and development are the Department of Defense (DoD), Department of Transportation (DoT), and the National Aeronautics and Space Administration. The functions of each agency are outlined in the following paragraphs:

The Department of Transportation is responsible for developing national transportation policies and programs conducive to fast, safe, efficient, and convenient transportation at the lowest cost. In addition, the Federal Aviation Administration, formerly the Federal Aviation Agency, is charged with: (1) regulating air commerce to promote its safety and development; (2) achieving the efficient use of the navigable airspace in the United States; (3) promoting, encouraging, and developing civil aviation; (4) developing and operating a common system of air traffic control and navigation for both civilian and military aircraft; (5) and promoting the development of a national system of airports.

The Department of Defense maintains and employs armed forces: (1) to support and defend the Constitution of the United States against all enemies; (2) to insure, by timely and effective military action, the security of the United States, its possessions, and its areas of interest; (3) to uphold and advance the national policies and interests of the United States; (4) to safeguard the internal security of the United States.

The principal functions of the National Aeronautics and Space Administration are: (1) conduct research for the solution of problems of flight within and outside the earth's atmosphere, and develop, construct, test, and operate aeronautical and space vehicles; (2) conduct activities required for the exploration of space with manned and unmanned vehicles; (3) arrange the most effective utilization of the scientific and engineering resources of the United States with other nations engaged in aeronautical and space activities for peaceful purposes; and (4) provide for the widest practicable and appropriate dissemination of information concerning NASA's activities and their results.

SECTION IV

CIVIL AVIATION R&D NEEDS

The rapid growth of the air transport industry has produced not only significant benefits to the public, but also a variety of problems. The major problems of civil aviation, as identified by the CARD Policy Study Report, are noise abatement and relief of congestion in areas of high traffic density. Another important problem area requiring increased R&D emphasis is short-haul service in a low-traffic density area. Continued R&D effort is required in the areas of long-haul transportation, air pollution, air cargo, general aviation, and broad based technology programs necessary for all elements of civil aviation.

This section will outline the R&D efforts that will be required to achieve the civil transport aviation goals identified in the CARD Policy Study Report.

NOISE ABATEMENT

Public awareness of the surrounding environment has impacted nearly all industrial concerns in very recent years. The public has become unwilling to tolerate any new technology and its application that tends to degrade the quality of the environment. Communities have already begun to react by restricting the hours of operation at major airports and by strong resistance against any new development of airports. The inability of the airport to expand has only compounded the problems in other areas of air transportation. Solutions to noise abatement problems will aid in solving other problems by convincing the public of the importance of new technology applications. The R&D needs, as stated in the CARD Report, in noise abatement can be divided into three general areas: source noise, flignt path control, and receiver noise.

- Source Noise

The major noise sources are found in the propulsion system and include: the primary exhaust stream, the fan exhaust stream, the fan and compressor forward-radiated blade noise, and the fan aft-radiated blade noise. Devices that produce significant noise reduction must change the mechanism through which the noise is generated, or provide attenuation of the sound after it is generated. A program is needed to investigate basic noise generating mechanisms to provide the identification of a source, the characteristics of the noise, and the particular effects associated with that noise.

- Flight Path Control

In addition to the reduction in noise which can be achieved as a result of source reduction, significant contributions to overall noise abatement can be realized through changes in operational procedures. The basic premise for these changes is the removal of the aircraft from noise sensitive areas. Research and development programs will be needed to develop aircraft flight procedures, airborne avionic systems, and air traffic control procedures and instrumentation which will permit new operations. Research and development in aircraft flight procedures must include numerous operational evaluations, as well as concurrent programs in airborne avionics and air traffic control systems.

- Receiver Noise

Receiver response research and development is the determination of the effects of noise on the surrounding community and the development of methods to predict community reaction to noise resulting from air transport operations.

The evaluation of noise effects is a complex problem involving the basic properties of sound and the factors which affect the reaction to a particular sound. Possibly, the most important variable in evaluating noise effects and developing noise-impact criteria is the psychoacoustic impact of noise.

There are presently several measurement scales for defining noise-impact criteria. The development of effective perceived noise level measured in units of EPNdB appears to have potential, but it lacks the accurate ability to assess psychological reactions to noise.

In conjunction with the above mentioned areas, the development of land-use planning techniques is necessary. Land-use planning will combine the efforts of noise effects and noise impact to select the utilization of adjacent land areas. The forecasting of noise exposure and its impact will be most useful when developing new airports.

- CARD Policy Report Needs

The R&D requirements stated in the CARD Policy Report are the following:

- The need to improve the fundamental understanding of noise generation, propagation, and attenuation.

- The evaluation of the psychoacoustic impact of noise, particularly for V/STOL and other new vehicle concepts.

- The development of new concepts of vehicle and propulsion systems with minimum noise a basic design parameter.

- Research on the generation, propagation, and alleviation of the sonic boom.

- The conduct of environmental systems demonstrations.

- The need for additional acoustic research and development facilities.

- The need to develop instrument landing systems suitable for curved approaches, steep descent, and other operational techniques to minimize noise impact.

- The need to develop personnel suitably trained to solve complex acoustic problems and able to participate in new vehicle and propulsion-system design and development.

- The improvement and implementation of land-use planning techniques, operational procedures, and other means of minimizing the impact on the environment.

- The development of analytical methods for the evaluation of cost, social impact, and technical factors to permit optimization of the approach to the solution of the overall noise problem.

CONGESTION

The tremendous growth of commercial airline operations, as outlined in Table 1, has produced serious congestion in and around major airport terminals. Congestion manifests itself in two primary areas: airway operations and airport operations. In addition to the requirements to upgrade these operations, a new short-haul system could help relieve congestion in the areas of high traffic density.

- Airways Operations

The air traffic control (ATC) system includes all elements required to support air operations from take-off to touchdown. The R&D programs necessary will be outlined as near-term and future programs. Near-term developments are those which will be required by the mid-1970s, while future systems are those that will be needed beyond the 1980s. These programs have been extracted from the CARD Policy Report.

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Near-Term (Mid-70s)

In order to handle increased traffic capacity it will be necessary to increase the capacity of airports by operating from closely spaced, dual-lane runways and reducing the block of air-space assigned to each aircraft. This will require the upgrading of electronic and surveillance systems to permit all weather landings and departures using the above runway and airspace operation, including the development of an improved instrument landing system (ILS) based upon a beam scanning microwave system. This development will be even more important considering the need for an ILS suitable for steep, curved approaches as suggested in the noise abatement requirements. In conjunction with improved electronic and surveillance systems, there is a need to upgrade the ATC radar beacon system to increase the accuracy in determining the aircraft's position. Closer aircraft spacing will require research into the detection and reduction of wake turbulence in the airport/terminal area.

Air traffic control separation must be provided to all aircraft either IFR or VFR, operating in medium and high-density controlled airspace. The development of collision avoidance service from an automatic ground-based system will be a necessary development for a fully cooperative system. Present VHF voice communication systems for transmitting separation and collision avoidance data must be replaced by a ground-to-air digital communication mode.

Higher levels in automation will be required as the traffic level increases in high-density regions. These higher levels of automation will provide the much needed assistance to the air traffic controller in performing many decision-making actions and tactical control functions. Specific automation of conflict control, flow management, and safety monitoring is needed. The implementation of an automatic data link to transmit computer-generated control instructions directly to the pilot is also required.

Navigation systems will require upgrading and improvement. Improvements to expand the capacity of the VOR-DME navigation system and provide the signals required for an area navigation capability in the domestic airspace is needed. The scanning beam microwave landing system (MLS) will complement the area navigation system by permitting flexible approach routes and providing improved accuracy in approach guidance. In addition to an improved VOR-DME navigation system there exists a requirement for a low cost navigation aid using very low frequency (VLF) in areas where signal coverage is not available from the VOR-DME system. The area navigation capability can be enhanced by the development of a terminal precision VOR (PVOR) to improve the VOR accuracy. The development of an oceanic enroute navigation system will include the evaluation of the OMEGA navigation airborne equipment and the use of satellites to satisfy navigation requirements.

The advent of the short-haul STOL and VTOL systems will require certain air traffic control requirements unique to V/STOL systems. The unique take-off and landing characteristics of these systems requires the development of steep, curved instrument approach and departure routes and an all-weather automatic landing system. Area navigation must include low-level navigation and low-altitude air traffic control in the terminal area. Due to the fact that new airports (STOL ports) will be constructed and other smaller airports will utilize the short-haul system, there exists a requirement to develop an instrument landing system at all airports serviced by the short-haul system and suitable for both high-density and low-density operations.

Another important area which is sometimes forgotten because of its "every day" service operation is weather services. There is a requirement to improve terminal weather forecasts, develop an automated weather briefing, and apply R&D for weather evaluation and control.

The need to detect and avoid or dissipate aircraft vortices which cause wake turbulence has been mentioned earlier. An equally important terminal area requirement is the development of improved methods for fog dispersal.

Clear air turbulence (CAT) can be found anywhere and is becoming an increasing safety problem. Therefore, there is an urgent requirement to develop a reliable method of detecting and thus avoiding clear air turbulence.

To coordinate all of the above systems, research and development is necessary to define performance standards for that portion of airborne equipment that forms a part of ATC, navigation, communications, and data acquisition systems, and that is associated with each type of service (IFR, IPC, controlled VFR, and uncontrolled VFR).

Future Systems

The required long-term improvements are expected to come from research and development activities in three major areas: (1) the development and evaluation of new traffic control concepts; (2) the definition and analysis of various system approaches; and (3) the development of new technology to provide new and improved equipment capabilities.

R&D activities are needed to conduct a continuous assessment of the relative merits of new concepts of ATC and the related technology to assure the upgrading of the airways system and to minimize the possibility of making too large an investment in a system that may become

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prematurely obsolete. New ATC concepts include combinations of strategic and tactical control methods. Strategic control is the control of the flow of aircraft, while tactical control is the control of such tactical functions as headings, speed, and altitudes. In addition, it will be necessary to conduct systems-engineering, simulation, tradeoff studies (including new control concepts and approaches for optimum airspace utilization), and an economic evaluation of policy alternatives on system design and implementation methods.

The selection of concepts depends upon the development of advanced navigation, surveillance, and automated control equipment. Research is needed on ground- and satellite-based position determining methods for navigation and surveillance and for performing both functions at the same time. In particular, special attention should be given to highly accurate systems with good low-altitude coverage and performance compatibility with new landing aids. Other position determination methods which warrant research are: (1) new radar beacon techniques; (2) multifunction one-way velocity and distance measurement systems based on precision time methods; (3) multi-lateralization systems requiring transmission to more than one ground location; and (4) hyperbolic grid methods similar to those used by LORAN-C, LORAN-D and OMEGA.

Continued analysis and research on the impact of new classes of aircraft, noise reduction advances, and improved weather and turbulence detection methods will be required to maintain an effective systems approach to the overall problem of air traffic control.

- Airport Congestion

Airport operations divide naturally into two principal elements, the airside and landside. The landside element may be subdivided into segments at the points where passengers and cargo enter or leave ground transportation. Critical difficulty is arising because airport development and ground-transportation facilities have lagged far behind the development of air vehicles. To complicate the problem further, competition for available land and funds in large urban areas where airport congestion is more severe, coupled with environmental and jurisdictional problems, have seriously delayed the development of badly needed new airports. The R&D requirements for airport improvement, as outlined in the CARD Policy Report, are: (1) system engineering, simulation, and tradeoff studies; (2) airport airside (airfield); (3) airport landside (terminal); (4) airport/community access and egress; and (5) regional area planning.

Systems Engineering

New concepts require extensive systems engineering to determine operational and economic feasibility and to place new

concepts within the total system development by use of priority and tradeoffs. The development and evaluation of new concepts for airports to include the expansion of existing airport capacity is needed. Expansion of existing airport capacity may be special-purpose airports, off-shore airports, and STOL and VTOL ports. The systems approach should include models to study the flow of passengers and goods through various types of airports. An overall objective in systems engineering studies is to develop decision criteria on tradeoffs affecting the external design of airports for the interface with the vehicle, airways system, and access/egress.

Airport Airside

The research and development needs concerning airport airside operations are closely related to airway operations. Systems for improved weather services, detection of wake turbulence, fog dispersal and automated ground control are necessary. To increase airport capacity, the need for a closely-spaced dual-runway system has been identified. The accomplishment of this new airways operation will depend upon the ability to develop high-capacity runway/taxiway configurations to include high speed turn-offs. New runway/taxiway configurations must include the development and test of pavement designs, improved methods for handling accidents, improved techniques for clearing runways of snow and ice, and improved methods of controlling birds around the runways.

The development of ramp/gate design guidance and criteria is needed to optimize time and cost factors. Included in the design guidance is the development of methods and equipment to improve aircraft servicing at the gate, to reduce noise and pollution, to decrease turnaround time, and to reduce vehicle count at any one gate.

With the introduction of STOL ports, new or improved techniques and materials are needed for elevated or off-shore STOL port construction, maintenance, and operational effectiveness. New STOL ports and other airports utilized to increase the capacity of the short-haul system will require the development of ground-based safety support systems (fire-fighting, lights, arresting gear, crash, and rescue) that could be pilot-activated at both attended or unattended facilities.

Airport Landside

The predicted growth in air traffic will impose a tremendous strain on airport terminal facilities in terms of passenger, cargo and baggage handling, automobile parking, and curb space.

Research and development is needed to minimize passenger- and baggage-processing time at the airport by providing appropriate

terminal area design criteria. Development of new or improved passenger-cargo and baggage-handling techniques which utilize terminal-flow simulation and analysis models to identify the particular needs of various types of passengers will be required to reduce total trip time. Minimum levels of service should be developed as guidelines for terminal design.

Airport/Community Access and Egress

A visual inspection of any major airport identifies an important contributor to congestion - the crowded access/egress routes between the airport and the community. The solution to the above problem will be complicated, but it can be aided by the development of improved methods to forecast demands for passenger- and cargo-handling services and improved methods and techniques to handle large traffic flows.

Regional Area Planning

Regional area planning will require the development of long-range models to evaluate the effectiveness of totally new air transport system concepts and the generation of planning criteria for airport development. This will include the development of planning methods to determine total regional air transportation demand and the distribution of the demand within the region on a quantitative basis. Also included will be the investigation and identification of approaches and procedures to implement airport plans through cooperation and coordination with state and local authorities to maximize the possibility of timely system development.

HIGH-DENSITY SHORT-HAUL SYSTEMS

The use of air travel for short trips (less than 500 miles) has increased sharply in recent years and has the potential to continue this rapid growth if certain problems can be solved. Air systems have the ability to take over the large short-haul market because they can respond to route demands much easier and faster than any other mode of transportation. The problems of short-haul transportation are: (1) the high direct operating costs to fly short distances; (2) the amount of time caused by airport congestion and access congestion represents a major portion of total trip time; (3) and the public opposition to airports close to populated areas increases the airport access problem.

The high-density short-haul system will probably result in the development of short take-off and landing vehicles (STOL) and vertical take-off and landing vehicles (VTOL). The vehicles alone will not be enough to answer all the problems of short-haul travel, but must be

accompanied by new airport and air traffic control systems designed specifically for these type vehicles. The CARD Policy Study identified R&D programs for improved short-haul systems covering all system elements: (1) air vehicles, (2) air traffic system, and (3) airports.

- Air Vehicles

Considerable R&D will be required to make STOL and VTOL aircraft comfortable and economically feasible with low noise and pollution levels, for operation in high density areas.

STOL Systems

Powered lift aerodynamics for STOL air vehicles has not been completely answered yet, but research in the area is continuing. At present the concepts of augmentor wings, jet flaps, externally blown flap, and direct lift need to be tested to evaluate the aerodynamic performance of each concept. The powered lift concept must not only produce a vehicle with a high-lift coefficient, but also a vehicle capable of higher cruise speeds. The development of reliable thrust reversers which exhibit low aerodynamic interference is needed.

The control and stability of STOL vehicles must be developed to insure safe reliable operations. The interaction between cross winds and thrust reversing will create major control problems. The investigation of aircraft control in the event of engine failure during take-off and landing is essential to the safe operation of powered-lift devices. With the advent of STOL, flight in adverse weather will require not only advanced controls, but a new line of sensors so that the safety envelope will not be exceeded. The development of experimental or prototype aircraft to conduct flight tests or studies of operational problems of jet-lift STOL vehicles is needed. Demonstrations to insure public acceptance of these vehicles in terms of cost, noise, safety, and ride quality must be conducted.

V/STOL Systems

For many years vertical takeoff and landing (VTOL) vehicles have been under investigation. The helicopter has proven to be the only operational VTOL vehicle available today. However, with the promise of a large short-haul market and new developments, the V/STOL vehicle is a promising concept. Noise problems and control/stability are essentially the same for both STOL and VTOL aircraft.

Advanced helicopter research and development is needed to provide a vehicle for short-range use. Efforts should be oriented toward cost reduction of the system and improved ride quality due to vibration and buffeting. Active controls will be a significant factor for the helicopter.

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Much research and development is needed in the operational lift-fan engine. The engines must have high (12:1) thrust-to-weight and high (400:1) thrust-to-volume ratios, which are double the values of current CTOL cruise engines.

Experimental aircraft must be built for new V/STOL vehicles to study the operational characteristics and problems related to each concept and to determine vehicle/market trade-off studies.

Air Traffic System

The air traffic system for short-haul operations must be compatible with the long-haul system. Particular emphasis should be placed on the following:

- Steep and curved instrument approach and departure routes.

- Area navigation and low-altitude air traffic control in hub areas.

- All-weather and automatic landing systems.

- Instrument landing systems at all airports served by the short-haul system and suitable for both low-density and high-density operations.

Airports

Short-haul requirements for airports must be compatible with other mission systems. The principal goals are to achieve:

- Airport designs that provide for maximum safety, to include arresting systems for elevated STOL ports and VTOL ports.

- Efficient passenger/cargo processing, to assure that maximum benefit is attained from reduced total trip-time capability.

- Ground access systems fully compatible with STOL ports and VTOL ports located within congested urban areas.

LOW-DENSITY SHORT-HAUL SYSTEM

The low-density short-haul system is very much an economic problem. This system is composed of cities with relatively few passengers per airport and a route structure of many short stage lengths. Passenger revenues do not compensate for the indirect costs of maintaining ground facilities nor direct costs such as take-off, landing, and

servicing. Equipment utilization is also very poor in the low-density system. Most of the equipment is either old or has been designed primarily for long-haul operation. In addition, regulations such as gross take-off weight limits constrain the capacity and performance of the system.

The major research and development effort, as stated in the CARD Policy Report, should be in the area of materials and structures (including fail-safe structures) to provide for the manufacture of safe, efficient aircraft at a minimum cost. A vehicle conceptual analysis should also be conducted to determine the vehicle design and gather operational data for the economic operation of a low-density short-haul system.

OTHER IMPORTANT AREAS

In addition to the foregoing areas identified by the CARD Policy Study as priority items, the CARD Policy Report outlined the following areas which require continued attention: long-haul systems, air pollution, general aviation, air cargo, and a broad technology base for air vehicles.

- Long-Haul Systems

The long-haul system has historically been the economic backbone of the air transport system. The most important contributor to the growth of air transportation has been the air vehicle. Each new aircraft represents a technological advance in aircraft size and speed which has resulted in productivity increases in terms of passenger-hours and reduced operating costs. The following discussions will be aimed at the research and development required for an advanced air transport for overland operations and a second generation supersonic transport, as stated in the CARD Policy Report.

Overland/Transonic

The advanced transport will require R&D programs in aerodynamics, propulsion, and structures to reduce noise as outlined earlier in this appendix. Research is needed to design vehicle configurations which will operate effectively near the speed of sound.

Automated methods of structural design and fail-safe structures are needed. Research and development on new lightweight, high-strength, high-stiffness structural materials such as fiber composites is also needed.

Flight tests will be required to validate research results. Large structural specimens must be built and tested. Supercritical aerodynamics have been developed in a laboartory environment, but flight

testing is needed to validate the supercritical-wing concept. Additional flight research will be required to assess new transport configurations, elastic structures, high-lift devices, and lateral-control.

Second Generation Supersonic

Research and development for an improved supersonic transport should focus on developing propulsion system technology to produce lighter engines with lower specific fuel consumption, higher transonic thrust, and reduced noise. The use of methane as a new fuel is very attractive. Its high heating value and greater cooling capacity warrant the exploration of its technical feasibility. Studies of new fuel logistics systems, different fuel handling techniques and storage, and modifications in aircraft design must be undertaken.

Structural research should be aimed at lighter materials and fail-safe structures with temperature capabilities to allow speeds up to Mach 3. Aerodynamic research on improving the lift-to-drag ratio and on configurations and techniques for reducing the sonic boom are necessary.

● Air Pollution

In the same fashion which has brought about public reactions to noise there is a growing concern over air pollution. Although many arguments are presented which show that aircraft contribute a small amount to total pollution, the growing number of aircraft and aircraft operations will probably increase the percentage contribution. The CARD Study Report has outlined the R&D needs in the area of pollution to: (1) improve aviation fuels and engines, (2) lessen the amount of pollutants emitted, and (3) eliminate noxious emissions. Attention should be given to the problem of air pollution very early in the development phase of an aircraft engine. Specific R&D efforts stated in the CARD Policy Study are:

- Control of visible pollutants by improved fuel and air-flow distribution, vaporized burner design, or fuel additives.

- New combustor concepts for increased combustion efficiency at low power needed to reduce non-visible pollutants.

- Determination of the effects of temperature and combustion dwell-time and their relationship to the production of oxides of nitrogen.

- Development of high-density, short-length combustors.

- Evaluation of combustor conditions to determine species distribution for a minimum-emission design.

- Better understanding of processes controlling engine emissions.

- Evaluation of emission effects in and around the airport, and the effect of aircraft emissions on the upper atmosphere.

- Research necessary to establish effective and practical regulations which are time-phased emission standards for aircraft operations.

- General Aviation

General aviation includes all civil flying other than certificated transportation. The aircraft used in general aviation operations extend from unpowered gliders and single-place piston aircraft to jet transports and helicopters. Since large numbers of such aircraft occupy the same airspace as certificated transports, R&D is needed to assure that these aircraft can use the technology developed for more sophisticated aircraft. The R&D efforts recommended by the CARD Policy Study are aimed at safety and air traffic control.

Safety

The application of new technology in propulsion and crashworthy airframes, and the application of aerodynamic design to improve stability and handling qualities will increase the safety of general aviation aircraft. Research should be initiated to develop improved training curricula and training aids for private pilots. In-depth analyses of the psychology of flight and methods to develop low-cost proficiency evaluation are needed.

Air Traffic Control

Research and development is needed to develop a fully cooperative air traffic control system to include the standards required of avionics systems. Emphasis should be placed on the development of an operational proximity warning system. A low-cost navigation aid utilizing very low frequency is needed in areas where VOR-DME navigation signal coverage is not available.

- Air Cargo

The CARD Policy Study recommended that little new R&D related to the cargo vehicle is expected to be required, however, designers should obtain the best aerodynamic performance and weight, consistent

with efficient cargo handling. Improvement of cargo handling equipment and facilities should include research efforts in containerization, materials and handling equipment, cargo terminals, and transfer to other modes of transportation. R&D is needed to develop a container light enough for air transportation while still having the strength for handling in all ground transport modes.

- Technology Base

A broad technology data base applicable to all types of air vehicles and missions is essential to the continued growth of civil aviation. Many of the problems already discussed will be dependent upon this broad base technology to assure timely solutions. The major disciplines, as outlined in the CARD Policy Report, are propulsion, aerodyanmics, operating procedures, structures and materials, and avionics. The following paragraphs will outline the R&D needs which appear in the CARD Policy Report.

Propulsion

In the propulsion area a major civil aviation R&D need is the development of lighter engines with reduced fuel consumption. Developments toward high bypass ratios, more efficient combustion, and more effective thrust reversers are needed. All engine development in the future must consider the factors which were discussed earlier: noise abatement and air pollution.

Aerodynamics

In aerodynamics the R&D needs are centered around improvements in computer techniques for the prediction of aircraft characteristics and the study of aircraft design concepts. In particular, the development of accurate theoretical methods for the new flight regimes (transonic to hypersonic) is necessary. Automated design methods are necessary in order to obtain aircraft with minimum structural weight. The lift-to-drag ratio (the measure of aerodynamic efficiency) must continue to improve for all air vehicles. Research is also needed to devise methods of reducing wing-tip vortices.

Operating Procedures

The discussion on noise abatement has already identified the need for new operating procedures and the necessary development in airborne avionics and air traffic control equipment. The all weather capabilities and improved safety of these new procedures and instrumentation must be developed and demonstrated prior to operational use.

Structures and Materials

Research and development in structures and materials must be aimed at reducing the structural weight of the air vehicle and the cost of fabrication. New structural configurations will be necessary for future aircraft, especially air vehicles involved in supersonic flight. New materials are becoming available and basic research will be required to investigate their properties and capabilities. In conjunction with new configurations and materials, fabrication and inspection techniques must be developed to insure fail-safe vehicles. Increased research is needed to insure the full exploitation of computer generated structural analyses for new configurations and complex shapes.

Avionics

Fundamental research in avionics systems is needed to increase reliability and decrease the size, weight, and cost of components. Emphasis must be given to the air traffic control system to include both ground based and flight avionics equipment to increase safety. Automation on board the aircraft and automating communications between the pilot and the ground will help to reduce both the pilot and air traffic controller workload. The development of an all-weather landing system would provide many direct benefits to other areas such as congestion and noise abatement.

SECTION V

MILITARY AERONAUTICAL TECHNOLOGY PROGRAMS

Military aeronautical research and development is basically oriented toward the development of complete weapon systems to support the national defense. Although military aeronautical R&D is aimed at military problems and not to the direct support of civil aviation, the technology produced for military programs in the aircraft industry is generally available for use in civil aviation. It has been recognized that specific mission differences exist between military and civil aviation, thus leading to different end products. However, the technology gained from production techniques and subsystem components, not to mention a broad technology base, has substantial benefit to civil aviation.

The development of any aeronautical system, either military or civil, depends upon the availability of technology. The accumulation of this technology base is a continuing process and involves many common items within both military and civil aeronautical programs. The list of areas in which the military conducts aeronautical technology programs is almost limitless in terms of aircraft systems and subsystems (e.g., navigation, communications, propulsion). The number of new starts for military aircraft adds to the design expertise and exercises the R&D capabilities of the aircraft industry. Considering the recent encouragement of military prototype aircraft programs, it is possible that the number of new starts per year for military aircraft will increase. These prototype programs will not only continue to upgrade and maintain technical capabilities within the aircraft industry by creating more competition, but will also aid in solving the economic problems many aircraft industries are facing today.

An important consideration in the development of an aeronautical system or subsystem is the technical risk involved. In developments for civil aviation, technical risk is translated into economic risk, which is sometimes unacceptable. Military equipment development tends to accept technical risk as necessary to achieve high levels of combat superiority or to alleviate a military threat. Early operational application in military weapons systems reduces the technical risk and hence the cost that would otherwise be encountered in applying the same technology to civil aviation.

The following discussion of current and planned military aeronautical technology programs which are relevant to the civil transport aviation R&D needs will be organized similar to Section IV. More detailed discussion and description of the programs to be identified in this Section is contained in Appendices 1 through 6.

NOISE

Military aeronautical technology programs relevant to noise abatement will be identified in the areas of source noise, flight path modification and receiver response. Source noise is subdivided into basic noise generating mechanisms, noise suppression techniques, quiet engine technology, and the generation and alleviation of sonic boom.

- **Source Noise**

The military currently has a series of programs for determining basic noise generating mechanisms. The research being conducted by the Army is almost exclusively related to rotary wing vehicle noise with primary emphasis on aerodynamically generated noise. The Air Force investigation of the dynamics of flow fields includes studies in aerodynamically generated sound, the noise generated by a transonic compressor row, noise from a linear array of large turbojet engines, and aircraft design utilizing minimum noise as a design parameter. In the propulsion acoustic area, the Air Force is investigating small turbine engine noise, jet noise reduction for military reconnaissance/surveillance aircraft, and noise from deflected jet VTOL aircraft. The basic acoustic theory research of the Army is directed at correlating theoretical results with experimental results, vortex shedding investigations, and the collection of high quality acoustical data.

The Army and Air Force are conducting noise generation investigations in rotor and propeller technology important for V/STOL and light aircraft. The Air Force technology programs include propeller vortex noise, the acoustic testing of a variable camber propeller, and the improvement of noise prediction techniques through basic noise source theory. These noise prediction techniques are aimed at propeller and gearbox system noise. The Army research effort is aimed at the development of a quiet helicopter. This quiet helicopter program will address both engine and rotor noise and is being sponsored by ARPA. Basic studies of rotor noise generation and propagation to include wind tunnel investigations are being conducted. Another Army program currently being pursued is the advanced technology for V/STOL propeller critical components.

Military programs related to noise suppression techniques are the prediction and control of aircraft noise, propeller technology, and the development of noise suppression equipment. The prediction and control of aircraft noise program includes helicopter acoustic and vibration surveys and the acoustic testing of noise suppression panels. The propeller technology program being conducted is directed at improving propeller noise reduction through utilization of unique propeller designs based on noise source theory. Efforts also include the definition, simulation, and reduction of near field noise environment from high lift devices on military STOL transports from the standpoint of its effect

on the structure. The Army acoustic efforts include piston engine noise suppression techniques. The Navy research efforts in noise suppression are aimed at the engine fan and compressor noise.

In addition to these research programs the military has initiated programs to provide for the manufacture of a large number of demountable and portable noise suppression equipment for use during ground maintenance run-up operations of turbine-powered aircraft and engines on test stands. The Navy is evaluating engine ground run-up suppressor concepts and the ground evaluation of inflight jet noise suppression concepts. The Air Force is currently developing equipment designed for use with the F-111A, FB-111, F-4, A-7, T-38, F-100, F-101, F-105, C-141, C-135B and F-15 aircraft and related engines.

Quiet engine technology programs are being conducted by all three service organizations within DoD. The Air Force program is for the development of a Medium STOL Transport (MST) engine which will include extensive efforts for noise reduction. Propeller technology programs are aimed at quiet propeller design procedures and quiet propeller concept evaluations. The Army currently has a program in quiet propulsion for helicopter and reconnaissance/surveillance vehicles. The Navy related program is a study in quiet propulsion for a quiet aircraft.

The generation of sonic boom is being investigated by the Air Force in a series of programs in supersonic jet exhaust noise. The objective of these programs is to develop a sufficient data base to provide better understanding of the basic mechanics of sonic boom generation.

- Flight Path Modification

The civil aviation R&D needs in aircraft procedures have been identified as the development of new approach and landing procedures and the related systems for a new instrument landing system (ILS), and the study of noise propagation along the flight path. The military have had and are continuing operational procedures which utilize increased glide slope angles, steep curved descents of helicopter, and two segment approaches for carrier landings. No detailed listing of landing system programs will be discussed in this section as they are the same efforts related to airway operations.

The military programs aimed at improving airborne avionics for an improved ILS include Integrated Communications, Navigation, and Identification (CNI), advanced avionics subsystems, aerospace vehicle information systems, and microwave and radar technology.

The military CNI Program contains the development of ground-air-ground and air-air communication systems, reliable data link for

data acquisition and transfer to ATC centers to provide near real-time command and control over airborne elements, and navigation in a three-dimension system. The development of advanced avionics subsystems will contain a multi-function microwave phased array system, the development of integrated cockpit displays, standardization of avionics items common to more than one system, and the development of new concepts that stress cost reduction. In the aerospace vehicle information system program, the development of a totally integrated information presentation and control system and digitally addressed flat plate displays are stressed. The current and planned program to improve microwave and radar technology has the objective of identifying and developing the radar sensor and microwave technology required to improve the performance of and provide alternative growth paths for avionics functions such as surveillance, navigation, guidance, and data transfer. Included in this program is the development of techniques and associated technology for deriving information from a microwave sensor, or combination of sensors, and arranging it in real time. The information to be provided includes position, velocity, geometry, identity, range and range rate, angle and angle rate, and other mission descriptors.

Current Air Force programs in the area of noise propagation are the biomechanics of Air Force operations aimed at the mechanisms of noise propagation, and the mechanical force environment program which is developing predictive data for sonic noise. The Army has a major effort in noise propagation related to helicopter operations. Two programs are currently underway, one of which deals with the absorption characteristics of the atmosphere. The second program is a research program designed to investigate the sound propagation and attenuation characteristics over vegetated terrain.

● Receiver Response

The research and development needs associated with receiver response to noise are the evaluation of the effects of noise on surroundings, development of refined noise-impact criteria, psychoacoustic impact of noise, and land-use planning. The area of receiver response to noise has been a project of the military for many years. In evaluating the effects of noise on surroundings, the Air Force program includes the effects of Air Force noise, the measurement of noise and vibration environments, mechanisms of noise generation and their reception, and the physiological response to sonic boom. The Navy has currently begun studies and measurements of the noise environment on aircraft carriers. The Army developments in this area are to minimize cabin noise, which in the current generation of rotary wing vehicles is very detrimental.

The achievement of more refined noise-impact criteria will be aided by military programs to study whole body effects of noise, effects

of acoustical stimulation of the vestibular system, effects on the vestibular system of acoustic energy, cell changes associated with temporary hearing loss, dynamic pressure chamber measurements, and an automated data acquisition system for noise measurement.

Air Force programs to study the psychoacoustic impact of noise are covered in the broad program area of biomechanics of Air Force operations. This program area includes the effects of operational noise, the control of human exposure to acoustic energy, auditory responses to acoustic energy, voice communications during inflight and ground operations, simultaneous exposure to acoustic energy and other stressors, human orientation during intense noise exposure, and the bioacoustic environments of USAF aerospace vehicles. Air Force scientists are also playing a major role in preparing and validating a major revision of the American National Standards Institute procedure for measuring acoustical performance of hearing protectors.

A major program in land-use planning was recently initiated to update USAF procedures to incorporate advances and refinements in the complex technical area of noise exposure assessment. This program includes efforts to obtain noise measurements on all current Air Force and Navy aircraft, development of computerized procedures to provide, on request, appropriate noise measurement data on aircraft, and appropriate corrections for pure tones in the noise and for duration of exposure. Upon completion of the above program, the Environmental Protection Group, USAF, is expected to establish a new regulation for the implementation of the refined prediction scheme and the computerized processing and retrieval of aircraft noise data. The objective of this Computerized Noise Bank is to revise methods in land-use planning with respect to aircraft noise to predict local community response to changes in noise levels resulting from Air Force aircraft operations. Future applications of these new methods will allow the locating of new aircraft to bases and the controlling of other aircraft operations in a manner to minimize noise disturbance. The approach will be to modify the Federal Aviation Administration's computerized noise exposure forecast (NEF) technique to allow it to predict the effect on the local community of noise caused by Air Force aircraft.

In summary, the military is conducting extensive research and technology programs in the area of receiver response to noise. In response to current environmental pressures the military has established new programs and re-emphasized continuing programs to reduce aircraft propulsion system noise. The military must respond to the public demand of noise abatement because military air bases share some of the same noise/community problems as civil airports.

CONGESTION

Although the military does not conduct R&D programs specifically

aimed at congestion, many of the problem areas identified in airway operations and high-density short-haul systems will receive direct benefits from military research and development programs. In the area of airway operations the military is planning to participate in joint programs with the Department of Transporation (DoT) to develop systems which are compatible with civil and military air operations. The best example of these joint programs is the development of a National Microwave Landing System.

- <u>Airway Operations</u>

The crux of all airway operations is the Air Traffic Control (ATC) system. The ATC system consists of surveillance, communications, navigation, weather services, and the automation of these same systems. Military R&T programs will be subdivided in the same format as the previously identified civil aviation needs. Near term programs will be discussed first, followed by future systems.

- <u>Near Term (Mid 70's)</u>

In the area of surveillance and landing systems, DOD is conducting extensive research and development programs. The Air Force is continuing developments for the Traffic Control Approach and Landing System (TRACALS). One of the most recent development eff associated with TRACALS is the AN/TPN-19 Landing Control Central System. In addition to TRACALS the Air Force is continuing work to improve the Air Traffic Control Radar Beacon System (ATCRBS)/Air Identification Mark XII Systems (AIMS) integrated system, and its Joint Advanced Tactical Air Command and Control System (JTACCS). Ground electronics associated with surveillance development efforts include lightweight radar technology, optical surveillance techniques, advanced recognition and detection system, and over-the-horizon (OTH) back scatter radar. This radar development includes R&D for an off-line signal processor, computer system upgrade, communications equipment, print-out displays, and tape editors.

The Air Force is also developing microwave and radar technology to identify and provide the technology required to improve the performance and alternate growth paths for avionics functions such as reconnaissance, surveillance, navigation, guidance, and data transfer. Included in the technical approaches are solid state amplifier development, thermionic sources, high data rate components, antenna elements, conformal arrays, target characterization, synthetic aperture techniques, optical processing, millimeter wave techniques and phased array radar. The Associative Processor developed under the Airborne Warning and Control System (AWACS) program is designed to provide a means of tracking and controlling a large number of aircraft. A larger, more reliable processor is currently under development.

The Navy has been involved in an extensive research and development program to provide an inflight monitor for their Automatic Carrier Landing System. This system, known as AN/SPN-41, will also serve as a backup for Category II landing operations. The AN/SPN-41 is a microwave scanning beam system. In addition to development associated with the ATCRBS/AIMS system, the Navy is developing a Traffic Management System Control and a light weight three-dimensional ground controlled intercept radar giving digital data concerning aircraft at long range and high altitude.

The Army Automated Air Traffic Management System (ATMS) project is composed of tasks for enroute, approach and departure control, and airborne subsystems. Priority is given to the air-ground digital data link task and the tactical landing system task. The development of an Air Traffic Management System Performance Model allows for system trade-off analysis and system optimization. The collision warning system task provides advanced development models of off-the-shelf equipment for evaluation. The flight instrument/display task provides for development and evaluation of flight directors, projected map displays, and other situational information devices. The Doppler task provides for the evaluation of new, lightweight, and low cost airborne Doppler radars which can be used to augment and improve existing and planned airborne navigation systems.

An equally important area of air traffic control is the air control center itself. The Air Force has various development efforts associated with the air control center. The TRACALS program is developing improved methods for tower display of altitude and identity information. Man/machine interface programs will aid greatly in developing more efficient displays and data handling methods in air traffic control centers. The Air Force also conducts research in the human factors area where the psychological and physiological tolerance limits for air traffic controllers is being investigated. The Air Force is currently conducting a competit'v : development program to investigate the automation of the tacti air control center.

The National Microwave Landing System (MLS) development has current or planned supporting programs from all three services. The general areas of support are the experiments using existing systems, signal format investigations, application to user needs, and related programs.

Experiments using existing equipment will be conducted as follows:

1. The Army will employ available Ku band scanning beam hardware to examine the influences of ground and other reflections on beam shape, accuracy, and guidance quality.

2. The Navy will determine the minimum data rate, with tracking radar, necessary to control and land an aircraft. Also, the Navy will use the AN/TPN22 X band phased array radar, in conjunction with its own AN/DPN-42 control system, to investigate the aircraft control feasible with scanning radar.

3. The Navy plans to conduct a flight test program to investigate the performance envelopes required of the MLS in a forward area V/STOL environment.

4. The Air Force will conduct signal format investigations using the Flarescan unit, a Varian narrow-band FM transmitter-receiver, and available laboratory equipment to quantify the effects of the dwell time of a single received beam passage on the accuracy of an angular measurement. In addition, this same equipment will be used to measure the effect of ground reflections for receiver elevation angles from 0 to 3 degrees.

The signal format area contains many programs related to user format, but the Air Force task to determine the minimum acceptable and optimum data rates as a function of information quality at the receiver output for various aircraft and control system configurations is applicable to all systems.

Planned applications to user needs will provide:

1. Determination of the guidance needs for steep, coupled approaches in a helicopter and the related landing guidance requirements with advanced displays - Army.

2. Studies to determine the most effective means of presenting guidance information available to the pilot on various forms of instrumentation - Navy.

3. Determination of the level of control and accuracy needed to complete a curved approach with Category II minimum - Navy.

4. Specification of signal processor functional requirements and the interface of receiver output with display instruments and flight control system. This will range from simple innovations for light aircraft at low approach to sophisticated cargo aircraft requiring zero/zero capability - Air Force.

The Air Force has an elaborately equipped CH-3E "flying laboratory" which is currently flying as a STOL flight profile simulator to define high angle STOL guidance, control, and display criteria. The first phase is underway and will provide glide slope and very accurate omni-range and range rate information.

Improvements in the air traffic control system will necessitate advances in navigation, communications, and automation.

Computer technology is continually being advanced by all three Services in DoD. Data processing (software/hardware, non-numerical, advanced technology, etc.) programs, increased storage and retrieval capabilities, and advanced multi-command data system are being conducted under DOD research and development. In addition to these "normal type" computer science improvements, the Army currently has a program investigating the use of computer administered instructions and commands.

Navigation and guidance systems receive constant research and development effort in DoD. New aircraft and their associated missions dictate continuous advancements in navigation and guidance. Airborne inertial and radio frequency navigation is being developed by the Navy. Advanced navigation aids are being developed and demonstrated by DoD. The Air Force is developing automatic terminal area navigation control schemes which include four dimensional (x, y, z, and time) coordinates for both transport and helicopter capabilities. Closely related to the ATMS is the Army Positioning and Navigation System (PANS). This program provides for the development of a common positioning and navigation system employing the LORAN position locator and the LORAN airborne receiver. In addition, the development of air traffic control tower equipment and aircraft airborne systems such as high frequency radios, radar altimeters, and special devices for developmental aircraft is included.

New air traffic control concepts and new operating procedures will require much improved communication links. Digital communication programs are being currently conducted by the Air Force and Army. The Air Force tactical command and control system is the development of a modular set of information processing and transmission components to establish an all-digital command and control environment emphasizing low cost and fast response. The Air Force Position Locating, Reporting and Control of Tactical Aircraft (PLRACTA) System is an information distribution system which is based on a highly connective (nodeless), high capacity, secure, and jam-resistant digital communications system. The Army is currently developing the TRI-TAC system which is a digital transmission and switching system characteristic of the principal communications requirements of the future. The digital approach has proven to be the best in providing an integrated and totally interfaced system.

The development of the above technologies will require concurrent development in the materials area. The Army plans the development of low loss, ultra compact delay lines and low drive power, remote control tuners for lightweight airborne communications; narrow band precision tuners and preselectors to provide greater channel capacity for communications receivers; and high density, low cost data storage

for data processing systems and computers with optimum cost, switching speed, access time, and power requirements. The Air Force plans include materials development work to provide improvements in:

1. Microcircuit technology for reduced size, less power and cooling requirements, and more reliability.

2. Optical efficiency and relaxed temperature restrictions to use light emitting diodes for indicator lights, alpha-numerics, and cockpit lighting.

3. The application of advanced composite materials to millimeter wavelength antenna systems for the development of high data rate and secure communications between the ground and satellite stations.

Common airborne avionics equipment will be discussed in the avionics technology base. An additional DOD development program is aimed at aerospace vehicle reference systems to provide reference information (position, velocity, altitude, attitude, acceleration and time) of sufficient accuracy and form to be usable by guidance, cargo delivery, flight control, stabilization, transfer alignment, and communication subsystems of aircraft. Equipment will be developed to provide a well defined set of GFE reference system sensors that can be functionally and physically integrated into the family of reference systems required.

The development of V/STOL air vehicles has necessitated some concurrent developments in the airway operations area. Most of these unique requirements are connected with the landing system and air traffic control system required for V/STOL operations.

The Army research and development program currently provides landing guidance systems for helicopters. The A-SCAN system evaluated to date, utilizes a scanning beam with extremely broad coverage providing for multiple approach paths. The system also includes a Distance Measuring Equipment (DME) function. Operational use of this system will be by 1976. The Army is also developing a self-contained navigation system to permit extensive low altitude flight with positive position fixing capability and day-night all weather operation. In addition, the Army is improving the Loran-D navigation system to include reduced weight, operation from portable land based positions, and the development of a new lightweight inertial navigation system. The Navy is planning research and development efforts directed at a V/STOL terminal guidance system for new STOL tactical aircraft.

In the weather service area, the need to detect and avoid clear air turbulence (CAT) is becoming more important as the encounters

with CAT by jet transports are becoming more frequent. The Air Force program of experimental investigations is continuing to study the nature of CAT at jet flight altitudes. The purpose of these studies is to develop improved techniques for forecasting CAT-prone areas and to establish the meteorological basis for the development of airborne devices to detect CAT ahead of the aircraft. Significant progress has been made in identifying turbulence with specific small scale meteorological features, but further progress will be aimed at increasing the knowledge regarding:

1. The time and space variations of the small scale meteorological features.

2. The relationships of these features with those on a larger scale.

A concentrated field observation program of an exploratory nature will be carried out with measurements from radar, aircraft, and meteorological observations. DoD plans to fly a B-52, an FB-111, and an F-4 in the wake of a 747 jumbo jet to determine the turbulence effects during a simulated multi-point refueling operation. The results of this simulation will contribute substantially to the effects of wake turbulence on trailing aircraft.

Supercooled fog (fog consisting of water droplets at subfreezing temperatures) restricts aircraft operations at airports during the winter months. The Air Force has led in developing an airborne seeding technique and then ground-based seeding to disperse such fogs. Based upon the success of both systems employed at various air bases throughout Alaska and Europe, the Air Force will conduct the engineering development of standardized, remote-operating, propane dispensing equipment for routine use of ground-systems at fixed air terminals. Warm fog (fog composed of water droplets at above freezing temperatures) comprises 95 percent of that fog in the United States which hampers airline operations. At this time, it is felt that heating a fog to make it evaporate holds the greatest promise for an operational system. Air Force plans include the investigation of the use of heated plumes to produce the necessary clearing of approach landing areas, and the development of a prototype system for warm fog dissipation. The Navy's Project Foggy Cloud is developing a warm fog dissipation system which will significantly improve all operations under adverse fog conditions. The program goals are to develop promising hygroscopic agents, spray systems, and techniques that will reduce or eliminate warm fog restrictions of ceiling and visibility.

The Air Force currently has a series of programs aimed at improving terminal area weather forecasts. A continuing program to develop a digital graphics capability as a part of the communications system to disseminate weather data is currently in the equipment testing

phase. The equipment was designed to transmit weather charts at a high rate of speed in order to increase their usability at Air Force bases and also to increase the capability for more traffic. The test equipment is capable of accepting either computer tapes or manuscripts for transmission, give the recipient a means of selecting or programming chart receipt at his own terminal, and give unattended operation. Existing plans are to deploy the digital graphics equipment to overseas areas upon successful test completion. The Air Force is also planning to replace the present manual weather briefings at base weather stations with remote briefings from the specialized Air Force Global Weather Central (AFGWC). Briefing equipment will consist of a telephone voice link, television screens for simultaneous display of a briefing to both the briefer and the pilot, and a teletype printer to provide recorded information to the pilot, to include computer flight plans. The Air Force plans to implement centralized briefing service to ten bases by late 1973. A third Air Force program to improve terminal weather forecasting is directed toward short range (0-3 hours) forecasts of local weather conditions that restrict or impair the safety of aircraft operations (e.g., low ceiling and visibility, strong surface wind, and severe local storms). Automated techniques will be used to acquire, process, and display surface weather observations. The objectives of the program are to determine the benefits of computerized radar and mesoscale weather observations, and to examine the consequences of compromise between network density and weather forecasting accuracy.

Programs to improve weather description and prediction include the following:

1. The Airborne Weather Reconnaissance System (AWRS) is intended to upgrade the capability of the Air Force to conduct tropical storm and routine aerial weather reconnaissance.

2. Project Seek Storm will develop an improved airborne weather reconnaissance radar system to collect vital data for the prediction of tropical storm movement and strength.

3. The Air Force development of a sensible weather analysis technique will provide the initial conditions for sensible weather prediction models. These numerical models will predict sensible weather rather than the pressure/contour patterns of the past.

4. The Army is developing a remote atmospheric sensing system to permit real time measurement of temperature, density, wind speed, and wind direction up to 50,000 feet.

5. The U.S. Army is now developing an Automatic Meteorological System (AMS) to organize available meteorological observations within a given geographical area and to process, summarize, and transmit, in near real-time, meteorological data.

The scope of the above meteorology programs clearly outlines an area where DoD research and development is aiding greatly toward solutions to civil aviation needs in the area of airways operations. To provide coordination between all current and planned military R&D programs, the Air Force has completed a Mission Analysis on Air Force Weather Mission-1985 to evaluate the impact of the natural aerospace environment on the Air Force and Army missions through 1985, and to determine the type and quality of weather support required for the 1972-1990 time period.

- Future Systems

Future Air Traffic Control Systems will require new ATC concepts and their relationship to new classes of aircraft and operational procedures. As new advanced aircraft are introduced into the military operational inventory, DoD will be required to develop new procedures and control functions for advanced helicopters, tilt-wing VTOL, STOL transports, and larger, more efficient cargo aircraft. These new procedures and control functions will have application to civil aviation operations.

Satellite communication and navigation systems are currently under development by DoD. Communication satellite programs include the development of a Stategic Survivable Satellite System, Defense Satellite Communication System, Tactical Satellite Communication System, and Fleet Satellite Communication System. The Air Force also has under investigation a Satellite System for Precise Navigation to provide highly accurate position, velocity, and time information.

Computer technology, as previously outlined, will continue to progress toward fail-safe systems. Higher capacity, increased processing speed, greater reliability, and integration with advanced data acquisition systems will be fundamental areas for research and development efforts. The Associative Processor techniques previously identified will be upgraded by developments of large capacity, high speed discs or drums and very large (trillion bit) core or semiconductor memories. This is just one example of computer science improvements which will take place in the next decade.

Complex and more sophisticated aircraft systems and their mission roles will continue to drive the military toward automated digital communications with air-to-air data links and ground/air/ground data links.

For the past three decades, DoD has been, and will continue to be, the sole agency that has provided aerial weather reconnaissance. As new classes of aircraft are identifed new weather prediction techniques and forecasts will be required. Future aircraft, such as a supersonic transport will fly at much higher altitudes (65,000 feet)

than present transport carriers. DoD has already gathered a vast amount of data to altitudes in excess of 80,000 feet and speeds up to Mach 3. DoD is currently involved, and will continue to be involved, in joint programs concerning flight tests and the collection of turbulence data. There seems to be little doubt as to the continued role of DoD in the weather service area.

- Summary

Military research and development efforts in airway operations will continue to have significant applications to civil aviation. The strongest areas of military contributions are electronic and surveillance systems for all weather landings, automation techniques, digital communications, navigation aids, and weather services. Equipment from military developments are not always directly applicable to civil aviation aircraft, but the R&D conducted and the technical risk assumed by the military are extremely valuable. New flight procedures such as two-segment apprach and takeoff, closely spaced dual lane runways, and a reduced block of assigned airspace will probably be demonstrated or validated by the military. In summary, airway operations will continue to be an important area for technology transfer between military and civil aviation.

- Airport Operations

Military research and development programs that are relevant to airport operations are those programs related to airside operations. Runway operations are a critical problem for both military bases and commercial airports. Military technology programs for pavement design and test, and runway clearance are directly applicable to airport operations. The Air Force is currently involved in a joint program, Combat Traction, which is investigating slipperiness criteria for runways, and developing simulation techniques for determining the stopping characteristics of an aircraft. In addition, the Air Force is responsible for generating runway smoothness standards. This includes development efforts for improving survey and instrumentation methods to determine runway smoothness as a function of time, traffic load, and weather. The Air Force is also involved in the studies of runway configurations.

Development efforts in base support and life support are also being conducted by the Navy and Air Force. Base support items such as aircraft hangars, electrical generation equipment, runway sweepers, heavy equipment, fire fighting equipment, and fuel handling techniques are all applicable to military and civil operations. Life support items such as protective clothing and acoustical head gear are under continuing development by the military. Problems related to aircraft servicing and accident handling are not peculiar to either military or civil aviation.

SHORT-HAUL SYSTEMS

The large short-haul market in civil aviation has not been fully exploited in the past due to the costly operational use of conventional takeoff and landing (CTOL) aircraft. In at least the high-density short-haul system, the development of short takeoff and landing (STOL) and vertical takeoff and landing (VTOL) aircraft seems to be very promising. These "new" vehicles have been under investigation by the military for a number of years. The following discussions will include the military R&D programs for both STOL and VTOL air vehicles. No specific discussion of engine noise abatement or air pollution will appear in this section as all pertinent environmental factors are discussed in other sections.

- Prototype Vechicles

The Air Force has received proposals for prototype development of an Advanced Medium STOL Transport (AMST). The objectives of this prototype program are: to evaluate military operational feasibility and utility of a medium-sized (C-130 class) jet STOL transport; to provide an option for modernization of the tactical airlift force by demonstrating technology in an operationally oriented system; to obtain visibility on costs associated with short-field performance; and to define STOL operational rules, safety rules, and related STOL design criteria for military use. The prototype will be designed to accommodate a 14-ton payload at an operating radius of 500 NM, operate from unimproved 2,000-foot runways, and have a speed of 0.75M. Data and experience from this program will be of value to civil development of STOL. Specifically, data should be obtained pertinent to: turbojet powered-lift concepts, STOL operations, control and flying handling qualities, cockpit configuration/controls, etc.

The Army has three current and planned prototype development programs related to V/STOL aircraft. The Cheyenne attack helicopter is currently under development. Although the Cheyenne has no direct transport capability, the development technology related to the rotor concept will be applicable to future vehicles. The Army is currently evaluating proposals for source selection for the prototype development of a Utility Tactical Transport Aircraft System (UTTAS) helicopter. The UTTAS will have a basic weight of approximately 9,500 pounds and the capability of carrying a squad (11) of combat troops and their

mission-essential equipment (240 pounds). The transport will utilize modular components, diagnostic fault equipment, and simplified maintenance procedures. It will have a flight safety reliability of almost 100 percent for a one-hour mission. The planned Heavy Lift Helicopter (HLH) will have a gross weight of approximately 115,000 pounds and a payload capability in excess of 20 tons. The helicopter will be capable of all logistics missions including ship to shore.

The Navy is strongly engaged in the development of an advanced V/STOL fighter aircraft and a longer endurance sensor platform V/STOL aircraft for the Sea Control Concept. Also included as planned efforts is a V/STOL support aircraft for ship to shore transport operations.

- Propulsion Systems

A new program has been initiated for the engine development for use in an Advanced Medium STOL Transport (AMST) aircraft system. The engine is in the 20,000 pound thrust class and program specifications outline significant improvements in engine performance, thrust/weight, pollution and noise control, simplicity, and maintainability. These improvements will allow the AMST to have significant improved operating economics and be capable of FAA certification. Another engine related development that is applicable to STOL vehicles is the Teledyne CAE Model 440-2 gas generator. It features an axial compressor followed by a centrifugal compressor, vaporized combustor, and two staged turbine. This gas generator technology is being developed for use in engines in light to medium gross weight logistics aircraft and lightweight fighters.

The Cheyenne attack helicopter was built around an existing engine. However, the Cheyenne was the first rigid rotor helicopter. The rigid rotor increases stability, has a low vibration level, and is quite simple.

The UTTAS prototype developments will all utilize the GE-12. This engine has a 1500 shp output and has an increased power-to-weight ratio over previous engines. Other advantages of this engine, include higher operating temperatures for higher thermal efficiencies and lower specific fuel consumption, and the use of high-pressure ratio sections in front of the engine to help increase power and reduce fuel consumption.

In addition to the prototype development programs, the Army and Navy are conducting propulsion system developments applicable to

helicopter and V/STOL operation to include:

1. The Army STAGG Program is to develop gas generators for a series of small engines, in the 1 to 2, and 3 to 5 pounds/second air flow class. Four contractors have been selected, two in each of the air flow classes outlined above. These gas generators are to be the "cores" of what will eventually be turboshaft engines for ground vehicles and small rotary or fixed wing aircraft. The approach the Army is using is similar to that of the Air Force in their ATEGG Program which results in a technology "stable" upon which engines can later be built for specific applications.

2. The Navy's Propulsion Component Technology (PCT) Program provides for the development of turbine engine components which will have wide propulsion applicability, and is directed to support related developments in the V/STOL area. This program is part of the Navy Aircraft Propulsion (Advanced) Program which includes two other projects: the first of which is Advanced Propulsion for V/STOL aircraft, wherein preliminary aircraft design will be studied to identify the V/STOL propulsion systems best suited for weapon system applications; and the second project covers an inflight fully modulated thrust reverser control system.

3. The Army has recently initiated a program to design, develop, make, and fatigue-test high-risk, high-gain critical components for an advanced technology V/STOL propeller system. An eventual goal of the program is to reduce the weight of an advanced propeller system by one-half from present standards, mainly with advanced materials and design/packaging techniques.

- Structures and Materials

In addition to its vehicle programs, the Army/NASA is conducting research and development efforts to improve helicopter and other VTOL vehicles. The Army/NASA is currently conducting research on analytical and experimental methods for controlling boundary layers and shock induced separation on transonic airfoils with particular emphasis on rotary wing aircraft. The Army/NASA is extending methods for predicting the dynamic response and transient aeroelastic response of rotor systems and V/STOL vehicles. Additional areas being investigated include Moire methods of stress analysis, instability buckling, and optimization of sandwich beams and vibration damping of light structures. The Army is also conducting extensive programs in fatigue and fracture that are directly applicable to the helicopter and V/STOL aircraft. Programs scheduled for near completion include the effect of corrosive environments on rotor hubs, rotor blades failure analyses, and experimental fatigue tests of composite rotor blades.

VTOL vehicles will benefit greatly from current and planned DoD materials programs. The advanced composites program will improve the critical thrust-to-weight and lifting-capacity-to-weight parameters. Without composites VTOL vehicles will pay significant weight penalties with adverse effects on speed, range, and load capacity. Rotor blades utilizing composites will achieve much greater reliability, durability, and reduced weight. Helicopter rotor systems fabrication and heat treatment technology for massive titanium hubs, shafts and spars will be established. Erosion resistant materials for rotor blades will be improved. The erosion resistance of composites can be provided by nickel coatings, but helicopter gas turbines are subjected to unduly short times between overhaul due to sand and dust erosion.

- <u>Ride Control/Stability</u>

The ride quality and control of the helicopter is being investigated by all three Services. The Army is conducting extensive programs to develop new rotor concepts and rotor vibration isolation systems for helicopters and advanced VTOL aircraft. The program goal is to achieve a 90 percent reduction in vibratory forces which are transmitted to the fuselage and passengers. The Navy is expending efforts to improve the understanding of airloads, including vibratory loads and other important parameters involving fatigue life, reliability, and survivability of helicopters. The Air Force program is aimed at developing design requirements and new dynamic analysis methods for new and unique rotor powered VTOL concepts.

Army flight control developments are primarily involved with helicopter applications. Hydrofluid augmentation schemes demonstrate highly reliable characteristics in the severe helicopter environment. More advanced blade control techniques such as boundary layer suction and blowing or pure jet flaps will be investigated. Means for reducing vibration modes induced by the rotor/blade combination will be explored from the active control standpoint. The man/machine interface program in the Air Force will investigate new concepts of vehicle control for VTOL aircraft with heavy emphasis on human factors engineering.

- <u>Other Research</u>

In addition to the above program, other VTOL related efforts are being conducted. The Navy is currently investigating the high speed helicopter rotor concept and the reverse velocity rotor which will allow speeds in the 300-400 knot range. Also included in the Navy VTOL program is an investigation of helicopter escape and survival to include escape from inflight emergencies, and protection from crash impact and resulting fires. The Army VTOL vehicle programs will develop and demonstrate much greater survivability for the UTTAS, and the HLH program will emphasize containerized cargo handling and a containerized logistics system.

The helicopter multiple function system (HELMS) is being evaluated by the Army. It uses a precision surveillance radar with the antenna mounted in the leading edge of the helicopter rotor blades, thereby eliminating the need for a dish antenna and radome. The high resolution provided by HELMS will have application for navigation and approach to unattended landing zones, weather avoidance and station keeping.

- Summary

The military R&D programs related to short-haul systems will have a high degree of compatibility with civil aviation needs. Unlike other air vehicle technology efforts, the military has undertaken prototype vehicle programs for short-haul systems. Both STOL and VTOL planned prototypes are underway. These prototypes will greatly aid in gaining public acceptance of using such vehicles for civil air transportation. Helicopters have already found their place in civil aviation through wide use in traffic control systems, medical evacuation, forestry protection, and short range travel. The rapid increase in heliport development substantiates the claim that helicopters and VTOL vehicles are becoming more important. New concepts in lift devices, structures and materials, increased stability, and improved ride control will have direct application to civil aviation and aid in the reduction of congestion.

In addition to the R&D program directed at STOL and VTOL air vehicles, the military is conducting extensive programs related to the unique systems associated with air traffic control of V/STOL vehicles. The Army and Navy scanning beam microwave landing systems are both important to the development of steep, curved landing control systems. As discussed in the airway operations section, the major efforts being conducted by the military for the National Microwave Landing System Program are directed at V/STOL operations.

OTHER IMPORTANT AREAS

The other important areas described in the CARD Policy Study as requiring continued attention are not areas in which military research and technology is lagging or non-existent. The largest contribution to civil aviation which military technology programs address is the establishment of a broad technology base. This broad base aids in ensuring that the technology will be available when a system design is proposed. Military research and development in other air vehicle areas, as well as air pollution, is being conducted.

Technology Base

Most of the major technological advances in military aeronautical research and development which have benefits in civil aviation are to be found in the air vehicle area. The large, broad technology base available in the air vehicle area today has been a direct result of 591

military aeronautical research and development. Recent planning techniques adopted by the Air Force will assure that the technology base will continue to be available to civil aviation.

The Air Force has introduced a new technique designed to maintain a close-coupled information flow between the laboratory scientist, who provides the forecast of technological advances, and the mission analyst and planner, who evaluates the future military effectiveness of a new system capability.

In order to develop and evaluate new concepts for advanced systems, it is necessary to derive a framework that relates state-of-the-art technology to mission requirements and then to fill in this framework with time-phased state-of-the-art technology and existing or forecasted mission requirements. Filling in the framework with existing information will provide two distinct results:

1. Missions that can be performed with existing and forecasted technology.

2. The technology required to match existing mission requirements.

When these two results are identified, the operating commands and the research and technology (e.g., Air Force Laboratories) oriented organizations can be consulted to determine the effects of a lesser increase in system capability, and the availability and cost of the increased technology to achieve a desired capability. The differences between the two systems can be resolved by cost effectiveness trade-offs. The final result is a technologically feasible system that can perform mission requirements. This planning technique can only be effective if a large technology base either exists or is being generated in several related technical areas. The related technical areas associated with aeronautical development are propulsion, aerodynamics, structures and materials, and avionics.

- Propulsion

In the propulsion area almost every military research and development program will contribute to the technology base for civil aviation. In terms of the specific civil aviation needs outlined previously, the military is conducting programs in all areas. The requirements for lower specific fuel consumption (SFC), increased thrust-to-weight (T/W), and lighter engines are not unique to civil aviation. The varied military mission requirements of speed, altitude, and endurance result in varying propulsion requirements in order to optimize critical performance parameters. If long distance is required, then SFC is important. If high maneuverability and acceleration rates are required, thrust-to-weight ratios and lighter propulsion systems are important. All future programs include methods for attaining lighter weights and lower SFC The planned development of high by-pass ratio fans, increased stage loading in the fan, compressor, and

turbine, higher turbine inlet temperatures (TIT), new materials such as composites in the front of the engine and high temperature alloys in the hot section, and advanced cooling techniques are all included in military development programs. In addition, the military has initiated new efforts aimed at noise abatement and pollution control.

In the development of advanced propulsion systems, a new approach has been defined to assure the exploitation and transition of advanced propulsion technology through the improvement of an existing engine or in new engine development programs at a reduced level of risk and at minimum cost. This approach is based upon developing advanced gas generator components (scalable compressors, combustors, and turbines) and system responsive components (inlets, fans, controls, power turbines, exhaust nozzles, and augmenters) which have a high degree of flexibility. These are combined in an advanced technology demonstrator engine to establish the propulsion, performance, and structural characteristics required for a class of military systems. This demonstrator engine will be flexible and scalable in both size and performance to satisfy the range of requirements by the various systems within the class. This new and revolutionary approach has been adopted by DOD and incorporated in the Air Force Advanced Turbine Engine Gas Generator Program (ATEGG), the Army Small Turbine Advanced Gas Generator (STAGG), and the Navy Propulsion Component Technology (PCT) Program.

Current and planned DoD programs in the materials area, as applied to propulsion systems, have general objectives to provide strength and resistance at increased temperatures and thus permit higher turbine inlet temperatures. Achievement of these goals will result in lighter engines or greater thrust to weight ratios. Specific programs related to metal alloys and metal matrix composites are to provide:

1. Continued development of dispersion strengthened alloys to provide strength and improved oxidation/corrosion resistance at higher temperatures.

2. Demonstration of newly developed wrought nickel base alloys for compressor and turbine discs.

3. Characterization of a new chrome-aluminum coating for super-alloys which provides a temperature capability of up to 2200°F.

4. Demonstration of composite blades to provide fan blading materials with increased stiffness to weight.

5. Characterization of high temperature creep resistant titanium alloys to include building and testing prototype engine parts.

6. Continued development of metal matrix composites to include exploitation of various phase reinforcement methods for application at temperatures of 600-1500°F.

7. Welding techniques for the high strength nickel base superalloys.

Specific Navy materials technology programs have the objective of a maximum temperature engine of 3500° TIT with 0.5 volume, 0.5 weight, and 1.5 specific thrust presently available. In addition, advancements are being investigated to reduce the cost of an engine by as much as 30 percent.

Propulsion advances must be integrated with airframe advances to optimize the aerodynamic characteristics of the total system.

- Aerodynamics

The technology base in aerodynamics or flight mechanics has evolved over the years and is essentially an updating process by the Navy, Air Force and NASA. In the area of aerodynamic drag, drag prediction methods are continually being updated as improvements are developed. Generalized aerodynamic prediction techniques are being developed for the complete design and performance of aircraft. Studies are being conducted to determine detailed needs for high Reynolds number testing. Wind tunnel-to-flight correlation studies are being conducted to arrive at accurate prediction methods. Several programs are being conducted in transonic test techniques to develop technology for obtaining more accurate wind tunnel test data. Primarily through the C-141 and C-5A development test programs, the Air Force found that the major factor affecting the limitations of data applicability was testing techniques in transonic facilities. A recent NASA-Air Force ad hoc group has assessed the areas where special emphasis needs to be placed to improve the accuracy and thus the reliability of wind tunnel facilities. In addition to basic shock/boundary layer interactions, the Navy is studying methods of integral relations for the development of transonic airfoil foil sections. Supporting transonic wind tunnel tests and wing/body optimization research is being conducted. The Army is presently conducting research on analytical and experimental methods for controlling boundary layer and shock-induced separation on transonic airfoils with emphasis on rotary wing aircraft applications.

The Air Force is pursuing a large effort in airfoil and wing theory. Accurate aerodynamic prediction programs for rapid analysis of complete configurations and modular prediction methods for analysis of specific areas is being developed. The following modular prediction methods are being developed or refined:

1. Boundary layer analysis, separation prediction, and resulting skin friction and pressure drag.

2. Drag prediction methods for complete configurations.

3. Drag due to lift prediction at high angles of attack and transonic Mach number.

4. Drag prediction of external stores.

5. Advanced airfoil pressure distribution prediction including high lift devices.

6. A wave drag prediction method which includes wing-body interference.

Aircraft engine compatibility programs are being conducted by the Air Force and Navy. The Navy is conducting research in the development of analytical methods applicable to the prediction of aircraft performance capabilities. Other Navy efforts are being directed toward development of VTOL aircraft technology.

The Air Force efforts are being directed at the optimization of the subsonic, transonic, and supersonic classes of vehicles and will evolve general technology that will be applicable to various commercial aircraft systems including transport and V/STOL applications. Particular programs for vehicles include:

1. Development of exhaust nozzle designs for optimum internal and external performance.

2. Documentation of exhaust nozzle/after-body drag characteristics.

3. Development of inlet drag and performance characteristics.

4. Development of analytical methods for the accurate predictions of aircraft performance capabilities.

5. Development of inlet/engine distortion sensitivities and assessments of installation compatibility. For increased engine/airframe interaction, the Air Force has developed a companion program to ATEGG - Aircraft Propulsion System Integration (APSI), which addresses system responsive components and engine/airframe compatibility and integration.

The technology base for propulsion and flight mechanics leads directly into the next airframe integration area - namely, structures and materials.

• Structures

The technology base for materials and structures is aimed at those programs which are not bound by any one flight regime - neither speed nor aircraft type. Many of the programs outlined here are more applicable to one class or type of air vehicle, but because of its overall nature the program will be identified in this section and not broken into smaller efforts to be identified with a specific vehicle.

The Air Force has generated and developed two large finite element general purpose computer programs - "MAGIC and FORMAT" - for designing aircraft. These computer programs are widely used by the aerospace industry and their capabilities are being periodically upgraded. The most recent Air Force computer design method has accelerated the optimization of structures for preliminary design. This Automated Structural Optimization Program (ASOP) will be extended in the near future to include compression panel optimization and strength and flutter constraints.

The Navy is maintaining a strong capability in structural design through selected procurement of recent improvements and innovations in structural analysis methods. The Navy is also pursuing an extensive program in interactive computer graphics.

Current Air Force research and development is underway to develop two new structural concepts employing adhesive bonding. One system is a combination of spot welding and bonded structure for typical sheet-stringer construction. The other technique is the development of laminated thick structural members made up of layers on laminates of titantium sheet bonded to each other with epoxy systems. Both techniques will provide fatigue resistant structural concepts. Other Air Force fatigue improvement programs will examine the effect of random loading, stress level, block size, and loading sequence on fatigue life and narrow band random fatigue information for various materials and structural joint configurations. The Navy R&T effort in this area combines theoretical and experimental programs to yield improved methods of fatigue life estimation.

The Air Force has an extensive program for the development of composite structures utilizing high strength, high stiffness fibers. The major portion of this effort has been directed toward epoxy matrix systems that have a temperature capability of 350°F. The Navy work is directed toward structural hardware using graphite filaments in an epoxy matrix. The boron/epoxy horizontal tail on the F-14 will be their first production component. In addition, the Navy

is presently conducting research on advanced analytical methods for determining actual dynamic characteristics of air vehicles by including optimized corrections based on measured data.

The Air Force program to apply finite element methods to fracture analysis will result in a capability to analytically determine stress intensity factors for two-and-three dimensional structural assemblies with flaws with local plasticity. Future efforts in this area will be aimed at methods for predicting plane stress and mode fracture, and the investigation of the behavior of flaws originating at fastener holes. In addition, a comprehensive experimental program is being conducted to supply basic stress intensity data, crack growth rates, crack arrest data for aluminum, titanium, and steel, and other substantiating data.

Structural configurations must also include vibrational studies. With respect to vibrational reduction the Air Force programs have been directed toward improving the accuracy of analytical methods for predicting high frequency random vibrations. Also, methods to control vibrations from sources of excitation such as noise and boundary layer turbulence will be investigated. The Navy effort is mainly oriented toward the development and improvement of structural response predictions to vibrations which are exicted by acoustic noise or turbulent flow pressure fluctuations.

The civil aviation R&D needs in structural materials are weight reduction, cost of fabrication, and utilization of new materials. Research and technology programs currently under investigation by DoD will emphasize the structural integrity of the aircraft and provide new materials which improve the strength-and stiffness-to-weight ratio of structures. The military will also continue efforts to produce metals with improved structural efficiency, creep resistance, stress corrosion resistance, and higher operating temperatures. Manufacturing methods for making advanced composites at lower costs, as well as advancing the use of composites into production aircraft through prototype structures, development, and service testing, will be continued. Continued effort on improving techniques for nondestructive inspection of metals and composites will be applied. Improved joining methods (adhesive bonding, diffusion bonding, brazing, glue-welding) will be developed and improved to approach 100% joint efficiency.

Other materials research and development programs that contribute to the structural technology base are listed below:

1. The performance and life of high temperature insulation materials will be established.

2. Seals and hydraulic fluids with higher use temperatures for future systems.

3. The application of fracture mechanics as a design parameter as well as the generation of design data will be accomplished.

4. Lightning strike protection for composites.

5. No maintenance aircraft bearing and finish.

6. Higher temperature plastic canopies (400-500°F).

The continuing efforts of design and engineering data generation will continue to be the largest contribution that DoD materials program will make.

- Avionics

Military sponsored or supported research and development programs in avionics has, for many years, provided a major technology base for subsequent commercial avionics development for civil aviation. This is exemplified by the current and projected development programs in the following general areas:

1. Aircraft Navigational System. The military-developed inertial navigation systems are now just beginning to be introduced into civil aviation.

2. Flight Control and Stability Systems. Self-adaptive flight controls developed by the military to improve the handling and stability qualities of aircraft are appropriate for the new generations of commercial aircraft now emerging.

3. Air Traffic Control. Programs relating to enroute position,locating,and reporting, as well as terminal area landing assistance are addressing compatible systems for both military and civil aviation.

4. Communications and Automated Data Systems. The evolution of high capacity, automatic communications and data systems, both voice and digital, are making major strides in the ever-growing communications traffic problems common to both military and civil aviation. This technology will be highly valuable for the planned Airways Communication Satellites.

5. Large Scale Integrated Solid State Circuits. The many integrated circuit device and component developments to meet the military need have direct application to an exceptionally broad spectrum of civil applications. Airborne digital computers, monitoring, and check out equipments are especially benefited.

6. Flight Safety Systems. Research and development in

high resolution landing radar, weather radar, collision avoidance, and turbulence detection under DoT and DoD sponsorship have direct application to civil aviation flight safety.

7. Miniaturization and Ruggedixation of Components. This work, carried on at many levels within DoD agencies, has the objective of more compact, lighter weight avionics equipment while providing greater reliability and reduced maintenance.

In addition to these general areas, the military supported research and development spans virtually all technical areas related to civil aviation requirements, including man-machine interfaces, instruments and displays, individual component improvements, very strong emphasis on reliability and self-test, improved manufacturing technology and many other areas highly significant to the development of civil aviation. Consequently, DoD initiates R&D efforts and accomplishes tests to prove the performance and reliability. Research and development must build upon the established state-of-the-art, with the objective of increasing capability, improving performance, and extending reliability and flexibility within the framework of systems in-being.

The military has many current and planned research and development efforts which will contribute to a broad technology base in airborne avionics technology. A complete description of individual programs will not be attempted here, but rather a brief summary of the technology goals will be presented.

The technical approaches to advanced avionic subsystems include the design of a multifunction phased array system, use of a single structure for CNI functions, and standardization of items functionally common to more than one system. The technical approaches to advanced avionics concepts include low cost, modular techniques, and automatic fault tolerant procedures.

The goals of vehicle information systems are to allow the automatic operation of the vehicle and critical functions in the flight profile and to be flexible with the mission, to include growth potential and low modification costs.

Goals in device and circuit technology include optimum performance coupled with high reliability and low cost, system improvements in UHF and microwave communications, and special devices to improve navigation aids.

The technology base in avionics peculiar to the Army has the objectives of obtaining data, determining feasibility, and applying new electronics technology to Army aircraft and ground based avionics equipment. Particular emphasis is placed on helicopter operations at night and during adverse weather. Major projects include: Navigation, Positioning, and Landing: Air Traffic Management; Aviation Communication; and Airborne Avionics Techniques. The latter project includes the investigation of environmental sensing, instrumentation displays, and flight control systems.

Specific areas in which Army studies and analysis are currently being conducted are radar, field of view measurements, and display techniques. Flight control studies on the handling qualities of large cargo helicopters will be conducted. Investigations of navigation computer techniques and hybrid techniques are currently being conducted. A detailed study will be initiated to define the man/machine interface requirements for the operation of aircraft at low level during night or adverse weather conditions. This study consists of simulation, limited flight testing, and the investigation of available techniques.

The technologies outlined above have concurrent developments in the materials area which are closely related and will aid in the development of hardware and software. Current and planned DoD materials technology objectives include:

1. 1000°F radome and radar absorbing materials.

2. Integrated, miniaturized, and ruggedized electronic materials.

3. Acoustic delay line crystals.

4. Improved higher temperature rain erosion coatings.

5. High temperature (1000 - 2000°F), high strength inorganic composites for electro-magnetic windows.

Additional equipment development, which is general to all missions, lies in the area of flight controls and collision avoidance.

- **Related Equipment**

Developments in flight controls and collision avoidance are items applicable to all types of aircraft and will be outlined in the technology base for air vehicles.

In the active controls area, the Air Force is developing active flutter suppression technology for application to aircraft where flutter critical components may be the wing, impennage, or a wing with external stores. Work is currently underway to develop the engineering techniques for the optimization of aircraft structures subject to constraints on flutter and strength. This method will apply to any flutter-critical aircraft component to achieve minimum weight for the actual aircraft. The development of unsteady aerodynamic methods for the accurate prediction of flutter instabilities is underway and includes interference effects between wing and tail for subsonic and supersonic flow and between wing-pylon-store for subsonic flow. The present Navy efforts in active controls are the development of fully modulated inflight thrust controls, auto-throttle investigations for carrier landings, and specialized automatic control modes for antisubmarine tracking tasks with both conventional aircraft and helicopters.

Army flight control developments are primarily involved with helicopter applications. Hydrofluidic augmentation schemes using fluidic logics rather than electrical computational techniques are being investigated due to their highly reliable characteristics. More advanced blade control techniques and means for reducing vibration modes induced by the rotor/blade interaction will be explored from the active control standpoint.

Digital flight control research and development is being conducted by the Air Force and Navy. The Air Force program is developing digital flight controls providing multi-mode optimization for tactical fighter mission modes. Navy R&D efforts include studies for digital flight controls for high performance fighters.

Air Force human factors engineering programs are focused on the man/machine interface problems. The current efforts will aid in the development of fast decision display techniques for airborne collision avoidance systems, and prediction displays giving the pilot better anticipation of aircraft future positions.

The military development of the Associative Processor for tracking and controlling a large number of aircraft is currently being evaluated by the FAA for collision prediction and avoidance. The Associative Processor is a computer system of storing and disseminating information at much greater speeds and at lower hardware and software costs than present day computers.

The FAA and DoD are engaged in a joint investigation and evaluation of all anti-collision system candidates for a national standard airborne collision avoidance system. Included in the evaluation will be the cooperative-type proximity warning system developed for Army helicopters and Secant technique now undergoing flight evaluation by the Navy. The air traffic control transponder technique for proximity warning will be investigated by DoD because of its low cost.

The joint investigation will also include ground based techniques for providing collision avoidance information. Two ground based concepts that offer potential are:

1. All aircraft would receive radar data from the air traffic control computers indicating the position of other aircraft that pose a threat. Only those potential threats would be displayed in the aircraft cockpit.

2. Ground computers to detect collision threats and to transmit automatically pre-recorded voice advice.

All the various pieces of the technology base for the air vehicle have been discussed. The common R&D efforts related to air operations and safety for takeoff and landing procedures will be discussed in the following paragraphs.

- Air Operations

The Air Force is deeply involved in efforts that are concerned with all weather landing and takeoff. Air Force development programs are aimed at developing new techniques for flight path control, particularly to overcome gust and windshear effects during low approach and to develop information display concepts, autopilot, and flight director system coupling techniques and piloting procedures for all types and classes of Air Force aircraft to include helicopters and STOL vehicles. Specific current efforts encompass the investigation of using forward looking radar as an independent landing monitor; experiments in crew/autopilot workload during IFR landing; flight investigation of the availability and usefulness of visual cues during zero-zero weather; and the demonstration of manual/automatic approach and landing capability for VTOL and STOL vehicles.

Future Air Force technology efforts include the investigation of new flight path control and flight director concepts, the analysis and flight testing of four-dimensional path control techniques, the use of inertial techniques to supply radio guidance smoothing and augmentation, and the simulation and flight analysis of numerous display concepts and pilot techniques for low visibility operations.

The Navy has a continuing program to develop and improve new concepts for an all weather landing system for carrier operations. This includes the development effort to improve the Air Traffic Control Radar Beacon System (ATCRBS) and integrate it with the Navy IFF (Identification Friend or Foe).

The Air Force will demonstrate new flight control laws for large transports operating in low altitude mission modes in wake and natural turbulence in a C-141 transport to increase safety in and around the air terminal area.

An additional Air Force development currently underway is the air-cushion landing gear. This new landing gear replaces the conventional wheels, tires, and brakes with a cushion of air which is maintained under the fuselage. This air cushion system allows the aircraft to land and takeoff from grass, snow, soft soil, and lakes. At present the system has completed flight tests on a small aircraft and is being installed on a deHaviland "Buffalo." This new landing system will greatly increase the safety of aircraft under all weather operations.

The efforts outlined above are only a small element of the Air Traffic Control System programs. In all of the functional elements discussed above, many items have been identified that are more important to one class/type of aircraft than any other. However, they have been identified as contributing to the technology base because of their potential applications to other types of aircraft. In certain specific cases development efforts may be mentioned again in the particular vehicle section if they are dominant forces in leading the development of a class of aircraft.

- <u>Long Haul Transportation</u>

The vehicles for long haul transports are divided into three types - overland; second generation supersonic transport; and hypersonic. The military R&T programs which will contribute the most to civil aviation needs are propulsion, structures, and materials. Structural design programs and materials outlined in the technology base for propulsion, structures, and avionics are also applicable to long haul vehicles and will not be discussed in the particular section.

- <u>Overland/Transonic</u>

A critical driving force for improved air vehicles in the overland subsonic/transonic region is the current efforts being conducted on supercritical aerodynamics. Supercritical aerodynamic investigations are being conducted by NASA/DoD. The Air Force is conducting both theoretical and experimental investigations of supercritical airfoil characteristics to include the effects of a

jet flap on a supercritical airfoil. Joint Air Force/NASA flight test demonstrations of supercritical wing technology using the TACT F-111 will provide data on a large variety of supercritical wings - airfoils, aspect ratios, wing sweep, etc. Additional supercritical wing development efforts of the Air Force include blended wing-body configurations and high aspect ratio wings which utilize advanced composite materials.

Programs being conducted by the Navy address both the problems of predicting supercritical flow about bodies, and the development of improved wing-body blending to achieve high efficiency in transonic flight. One specific concept being investigated by the Navy is the supercritical airfoil with an increased wing thickness that does not result in the reduction of the drag-divergence Mach number that normally occurs with increased airfoil thickness.

The Air Force is also working on other aerodynamic problem areas related to transonic flight. Several programs are addressing the problem of transonic buffet and the means to delay its onset and reduce its intensity. These programs will develop design critieria for the highly efficient aircraft which must cruise in this regime. Efforts in boundary layer control devices will reduce wing separation, keep the flow attached, and provide a substantial reduction in wing drag. The jet flap, slot blowing, and vortex generator concepts are all being actively pursued and offer aerodynamic improvements. In addition to basic shock/boundary layer interaction investigations, the Navy is studying methods of integral relations for the development of transonic airfoil sections. Supporting transonic wind tunnel tests and the associated two-dimensional test technique development will be performed.

In the structures area, the DoD is conducting demonstrations of structural composites by building and performing ground structural tests on scaled and full scaled components, flight testing experimental articles, and operational flight testing of production structural hardware.

The DoD is investigating the improvement of high lift mechanical and fluidic devices for landing, takeoff, transonic maneuvering, and cruise. In conjunction with the above efforts, advanced flight control devices are being investigated.

The Air Force has major developments underway in a Survivable Flight Control System emphasizing the attributes of quad-redundant fly-by-wire techniques. Highly responsive and ultra-safe controls are major program goals.

Research and development programs in the materials area for transonic flight are being conducted to provide:

1. High strength (300,000 psi) steel alloy forgings and minimum yield strength (85,000 psi) aluminum alloys.

2. Improved adhesive bonding to produce higher strength more durable bonds and improved joining techniques (mechanical fasteners, welding, brazing, etc.) to increase joint efficiency.

3. Flight and service testing of large size aircraft structures of advanced composites.

4. Nondestructive inspection techniques to find defects under fasteners without disassembly, to determine the quality and strength of adhesive bonding joints, and to develop portable X-ray units for inspection inside aircraft cavities.

5. An extensive continuing program on design data generation.

The B-1 advanced strategic bomber will have civil applications in the areas of engine and airframe technology. The propulsion technology will result in a short, lightweight engine. Engine developments of interest are the use of new materials such as RENE-120 and RENE-17 for compressor blades; a single stage high pressure turbine for a 12:1 compressor ratio; and improved turbine cooling technology. Airframe improvements will provide further knowledge of variable sweep, blended wing/body configuration concepts in a large aircraft. Structural mode control will be used to improve ride quality. Structural technology will demonstrate the reliability of various NDT techniques. Important data on producing and working titanium and highly fracture resistant materials will be obtained and made available.

The Air Force currently has three engine development programs applicable to the transonic/supersonic flight regime. These development efforts are all part of the Air Force ATEGG/APSI program previously outlined. The Detroit Diesel Allison Division is presently running the GMA-100 gas generator. This is a high efficiency and high pressure variable geometry compressor, with short combustor and two staged turbines. General Electric Company is testing the GE14/J1B1. The components include a highly loaded medium pressure ratio compressor, a carbureting combustor, and a single stage very high temperature film/impingement air-cooled turbine. The Pratt and Whiteny Aircraft PWA 535 is currently undergoing cyclic tests. This gas generator has an advanced transonic compressor with cantilevered stators and drum rotor construction, a premix combustor, and a high temperature single stage transpiration cooled turbine.

The transition from transonic overland flight to a second generation supersonic transport for civil aviation will be very dependent upon the success of noise abatement and pollution control

efforts previously outlined. Much of the vehicle technology is understood and the remaining is being investigated. The recent termination of the SST program will not have any major effects upon current and planned military R&D programs.

- <u>Second Generation Supersonic</u>

The most significant Air Force technology effort in the area of flight controls is the Control Configured Vehicle (CCV) Advanced Development Program which will develop and validate automatic flight control technology. For a large aircraft, the specific control functions to be developed include augmented stability for an aerodynamically unstable aircraft, flutter control, ride control, and maneuver load control. The interactions and compatibility of these control functions will be investigated. Flutter control is the extension of the LAMS technology to the control of unstable structural motions. The ride control development will provide the first flight experience with a ride system using dedicated miniature control surfaces and will provide the technology base necessary to integrate such capability into other systems performing other structural response control functions. Maneuver load control is the use of control surfaces to provide direct lift (positive or negative) during maneuver on various parts of the wing to minimize bending moments created by the maneuver.

The materials and structures efforts discussed in the technology base are applicable to the supersonic regime with increased temperature capabilities being investigated. Current Air Force efforts aimed at specific structural areas include polymer and metal matrix systems for use at high temperatures applicable to supersonic aircraft. Sonic fatigue information is being developed for incorporation into design methods. Work is underway to determine the effects of elevated temperatures on the sonic fatigue of structures which are located in or near the engine efflux. The present effort is investigating effects up to temperatures of 800°F, while future work will continue up to 1200°F. Planned and on-going efforts will further refine sonic fatigue design methods by the inclusion of several dynamic effects. Thus, the effects of multiple modes and dynamic non-linearities on random fatigue will be investigated. Programs to establish the validity of fatigue test time compression for supersonic aircraft will be completed in 1972. An exploratory flutter optimization program limited to supersonic speeds has been developed. Plans with NASA are underway for an overall integrated Procedure for Aircraft Design (IPAD) including aerodynamics, controls, structure, and propulsion.

In addition to the structural efforts being conducted, the military is continuing materials research and development programs which are applicable to a supersonic transport vehicle. Increased temperature capabilities (up to 2500°F) and increased life

(up to 30,000 hours) are specific goals in the developments of titanium, aluminum, and steel alloys. Improved joining techniques will include the development of high temperature (600°F) adhesives applicable to bonding and glue welding techniques. Techniques for inspection of defects in high temperature coated superalloys and refractory metals will be developed and/or improved. High temperature (1000 - 2000°F) stability of high strength (20,000 psi) inorganic composites and improved strength and stiffness of metal matrix composites at these temperatures will be further evaluated. Plastic transparencies for prototype aircraft window and canopies, integral fuel tank sealants, and seals for hydraulic systems will be developed for higher temperature (500-600°F) application. As the temperature capabilities of various materials are increased, extensive design data and engineering data for related structures will be obtained.

The CARD Study identified the possible application of cryogenic fuels such as liquid methane or hydrogen due to their capability of providing near maximum heat sink capability. The chemical and physical properties are well defined, but the application of these fuels to jet engines presents problems. While liquid methane has approximately 10% more btu/lb than conventional distillate fuels and liquid hydrogen has nearly 3 times the btu/lb of the distillates, they both are considerably lower in btu's per unit volume than present fuels. This fact, coupled with the cryogenic nature of methane and hydrogen, requires careful analysis to ascertain if the inherent logistical deficiencies are balanced by the higher heat sink capabilities. At present the military is not planning to conduct R&D on cryogenic fuels for jet engines. Presently available distillate fuels are used for operations up to Mach 2.5 and JP-7, a synthetic fuel, is available for operations up to Mach 3.5.

The Air Force is, however, conducting R&T programs for "endothermic-vaporizing" fuels. This type fuel would be a synthetically derived material which embodies the necessary thermal stability, vapor pressure, and catalytically derived heat sink so that it would provide cooling capacity up to ten times that of standard distillate fuels. This type fuel should provide adequate cooling for operations up to Mach 4.5.

The advances from supersonic to hypersonic air vehicles requires the same general research ideas - advanced propulsion and operation at increased temperatures. However, the incremental jump involves many more technological advances than are required for transition from transonic to supersonic.

- Hypersonic

Preliminary conceptual design studies have defined the general aerodynamic configurations for hypersonic flight. A hypersonic

test vehicle configuration has been extensively investigated to define the technologies essential for sustained hypersonic flight. Specific efforts are being conducted to accurately predict the aerodynamic heating environment for these vehicles. Of particular importance are regions of interference heating, shock wave impingement, and boundary layer transition. The growth test vehicle will be systematically designed to explore the hypersonic regime in incremental steps. The primary modifications required will be the thermal protection system and propulsion system. The Air Force/NASA X-24B will demonstrate subsonic, transonic, and supersonic characteristics of future hypersonic configurations.

The Navy Maneuvering Hypersonic Vehicle Configuration design study of lifting reentry vehicles contributes through the investigation of high heat load structures and attendant thermal protection system designs.

Current and planned DOD materials programs for high temperature insulation radomes, and high temperature alloy programs will aid in the development of hypersonic vehicles. High temperature airframe seals (2000-3000°F external) as well as high temperature glass and plastics for windows must be developed.

● Air Pollution

The previously identified civil aviation R&D needs in air pollution are engine emissions, emission effects, and the development of time-phased emission standards. Engine emission control can be subdivided into the characterization of engine emissions, improved fuel and burner design, and improved combustor conditions and design.

● Engine Emissions

The Air Force has undertaken a program employing laser Raman spectroscopy to develop an instrumentation system which will identify specific pollutants, under dynamic conditions, on a real-time basis and be packaged in a mobile unit. Future programs by all three services include the development of monitoring techniques and procedures for military toxic products in the general environment. Fuel additives are being investigated by the Air Force to reduce visible (smoke) pollutants and nitrogen oxides. In conjunction with the fuel additive program, modifications of the burner section of the J-79 are currently underway. Combustor design and operating concepts are also a part of the Air Force and Navy R&D programs. Military specifications for engine procurement have been written to include "smokeless" combustors. The term "smokeless" does not necessarily mean the production of absolutely no smoke, but rather the quantity produced will be below an acceptable level to both the military and civilian

communities. The Navy currently has a program to develop acceptable designs and prototypes for smokeless combustors and the retrofit of new combustor cans to eliminate smoke from the TF41, TF30-P-6, T56, J79, and J57 engine models. It is expected that by fiscal year 1976 all naval combat aircraft will be equipped with smokeless combustors. Planned Air Force work includes the development of short length/high heat release combustors and investigation of the feasibility of using a catalytic combustion scheme.

The Department of Defense has an additional program on the Control of Noxious Emissions (CONE) wherein all USAF programs that are investigating the various fields of air pollution control are reviewed and directed so that all existing avenues of air pollution are suitably addressed.

Another Navy program indirectly related to engine emission reduction, but directly related to air pollution, is the study of several systems to control emissions from jet engine test cells. A prototype of the most promising system is under construction. This system is expected to remove 99 percent of the particulate matter from engine test cell emissions.

The Army has established an aircraft emissions reduction program with the objectives of defining pollution abatement requirements of Army aircraft gas turbine engines and providing emissions reduction technology to meet those requirements. The overall approach is to measure the emissions of present and advanced technology prototype Army engines, to establish, by coordination with the EPA, emission level targets, and to conduct research and exploratory development of promising reduction concepts, culminating in demonstration of compliance with the reduction requirements.

- <u>Emission Effects</u>

The Air Force has a focused effort in propellant toxicology as it relates to the effect of environmental pollution on the population. Current programs and their overall goals are summarized below:

1. A continued program on the pyrolysis products resulting from the burning of otherwise nontoxic materials. The specific goals are to develop safety criteria, materials selection criteria, and prevention of environmental pollution.

2. A continuing program will determine the effects of military operations and chemicals as general environmental pollutants, and develop field dosimetry devices. Overall pollution control and abatement and the definition of environmental quality criteria are the specific goals of this program.

A Climatic Impact Assessment Program (CIAP) is currently being undertaken by several Government agencies. This program has a goal to conduct a complete assessment of the impact of supersonic, high altitude aircraft operations on the atmosphere and subsequently on the entire biosphere. Air Force and Navy participation is in the area of engine testing and the modeling of atmospheric physics. Another program directed at establishing aviation's contribution to atmospheric pollution from sea level to supersonic jet altitudes is to positively identify the source of a smoke plume. This program is being conducted by the Los Alamos Scientific Laboratory which is being assisted by the Air Force. The Air Force is experimenting with a wide variety of photographic film and developing techniques to determine the various characteristics of the plumes.

- Emission Standards

Future Department of Defense programs will include the improvement or development of monitoring methods with supporting technology and instrumentation for air contaminants of uniquely military origin. New pollution control processes, disposal systems and waste discharge standards for DoD pollutants will be required. The Air Force will emphasize the air pollution portion of the DoD work. In addition to the above instrumentation and processes, human exposure standards for materials which have pollution potential will be established. Any advances made by the military in air pollutants from engines will have direct application to the civil aviation environment.

- General Aviation

Many of the technology base items such as lighter weight engines, advanced control systems, and standardized common avionics will have indirect application to the general aviation area. A current engine development program which will have spin-off applications to general aviation is the Small Turbine Engine Development Program. This program is aimed at high performance small turbine engine technology and low cost. This program includes manufacturing technology aimed at lowering component costs through unique design, specialized fabrication methods, and high volume manufacturing processes.

In addition to these indirect benefits, the military has specific research and development efforts in the areas of safety and training.

All three service departments in DoD are active in human factors engineering programs, especially where the man/machine interface is critical. Current R&D programs in this area are directed toward reducing aircraft accidents caused by human error either in the cockpit or on the ground and improving "heads up" displays permitting the pilot to read critical flight data while maintaining outside vision during landings.

Flight training simulation is valuable to the overall safety problem in general aviation. Current military R&D is centered around the development of further improvements in visual simulation of what the pilot sees through his windshield. Efforts are being devoted to achieving higher resolution, larger angular coverage, larger geographical coverage, and computer generation and storage of the visual images. Another aspect of simulation that continues to receive attention is motion simulation and how to provide motion cues which will be realistic. A third general area of research is the measurement of pilot proficiency in flying the simulator as a means of predicting pilot efficiency in actual flight.

- Air Cargo

The Air Force has recently adopted a new technical objective for airlift operations. The most critical economic factor determining the value of airlift is the cost of delivery cargo in cents per ton-mile. Future technical developments will be oriented toward increasing airlift productivity while reducing the total costs. This objective will be incorporated in planned airlift vehicles. The MST concept is both a tactical and strategic airlift vehicle. Therefore, the aircraft will be designed to be weight limited instead of cube (size) limited. Efforts to improve cargo handling will include a "drive thru" cargo compartment and a self-contained loading system. The Heavy Lift Helicopter program will provide improved cargo handling techniques peculiar to transport helicopter operations.

The Army has continued to lead in the development of containerization. The major discrete logistics load for the military is the standard shipping container which has dimensions of 8 ft x 8 ft x 20 ft, and a carrying capacity of 22.4 tons. Application of this MIL-VAN container can be the first step toward an intermodal container for civil aviation use.

SUMMARY

The military programs which have been outlined in the foregoing paragraphs are the bases for the technology which is relevant to civil aviation. These programs are only meant to cover the "R" in R&D. Appendix 8 will consider the "development" portion of R&D. Although many research and technology programs relevant to civil transport aviation have been identified, when and how they will be applied to civil aviation is very much a question which can only be answered by the development of hardware and components. The technology transfer process itself is very dependent upon development and thus the technology relevant to civil aviation needs can only be a partial answer to the question of military R&D relevancy to civil aviation R&D needs.

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APPENDIX 8

MILITARY DEVELOPMENT RELEVANCY
TO
CIVIL TRANSPORT AVIATION

JOINT DoD-NASA-DoT
"R&D CONTRIBUTIONS TO AVIATION PROGRESS"
(RADCAP) STUDY

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APPENDIX 8

MILITARY DEVELOPMENT RELEVANCY

TO

CIVIL TRANSPORT AVIATION

SECTION I

INTRODUCTION

The application and/or transfer of aeronautics technology and hardware from military programs to commercial aircraft design and development will be considered in this portion of the RADCAP Study. In order to accomplish an assessment of this question, six case studies are considered. Four of the case studies are the Boeing 707, Douglas DC-8, Boeing 747 and Douglas DC-10. The other two cases consider a projection into the future by estimating the amount of technology and hardware transfer which will likely occur for the development of a commercial STOL transport and an advanced supersonic transport. This study will discuss the nature, timing and trends of this process and assess the amount of hardware transfer that actually occurred in the development of the commercial transports mentioned above. Much background data were reviewed and discussions were held with high level engineers at the Boeing Company and McDonnell Douglas Corporation, in order to present an account of the transfer of technology, development base and hardware.

By necessity, to advance and meet future needs, the military was the first to undertake the development of large jet powered aircraft. By the early 1950s the rapid advancement made in turbojet engine development and demonstrations of high speed flight already had set the stage for large aircraft economical enough to use as commercial transports. Some of the forerunners of higher subsonic speed aircraft were the F-86s, B-47s and A-3Ds. These airplanes provided the technology and demonstrated flight handling characteristics for high subsonic speed flight and could be considered as the predecessors for large jet aircraft to come such as the 707, DC-8 and later the DC-10 and 747. However, it can be said that the present generation of commercial aircraft represent an evolution from military designs such as A-3Ds, B-47s, C-135s and B-52s and that the commercial transports, in the future, such as the medium STOL transport and an advanced supersonic transport will derive some of their technology base from military R&D programs such as the SR-71, XB-70, B-1, F-14, F-15, Advanced Medium STOL Prototype and the NASA/Boeing C-8A Augmentor Wing Research Aircraft. It can be argued that the technology base and most of the advanced development evolves from military R&D but the specific hardware bits and pieces do not. The transfer of hardware or the bits and pieces is minimum in the present day large jet airliners such as the 747 and DC-10. The largest transfer which takes place is technology know-how, design data, military specifications and design criteria. However, it must be said that large jet engines have had their "start" as military programs and a high amount of hardware transfer has occurred. The aerospace industry involvement in conducting military R&D programs advances the state of the art in the aeronautical field. Therefore,

a major portion of the technology is generated from the R&D programs funded by the military, NASA and DoT. The results of these efforts furnish advanced aeronautics technology, provide technical data and most important indicate the way not to go.

The establishment of an advance technology base is one of the most important aspects for things to come in the aeronautics field. From technology programs, those that are intimately associated with their respective disciplines gain an understanding of the subtle design points and how to apply these to the design of an aircraft. The refinements required to establish the particular operational capability of aircraft components will be developed through simulation and ground and flight testing. Without the technology base concentrated in a design team, one could not undertake a program of designing future commercial aircraft with success. It is very difficult to establish a numerical percentage of importance to this bank of knowledge, but it is acquired through doing innovative research and development.

R&D efforts supported by the DoD, NASA and DoT have provided more than 75% of the technology know-how; more than 50% of the experimental development and more than 25% of the manufacturing and production.

During the past twenty years the amount of transfer of technology or hardware depended, to a great extent, on the amount of military versus commercial business in which an aerospace company was involved. In the early fifties the Boeing Company was accomplishing more than 50% military development and production; in the seventies, this trend has changed to approximately 15% military business. Consequently, the transfer of hardware is minimum. Over twenty years ago, the majority of the facilities in a company ,such as Boeing or Douglas, were facilities owned primarily by the Air Force. Today, the percentage of facilities owned by the military is much lower. For example, the Boeing-Everett Plant, where the 747 is produced, is 100% company-owned.

If a more specific approach to the problem of hardware transfer is taken, one can begin with the Boeing Company and the Model 377 Stratocruiser. These efforts began with the development of the B-29. Then the XC-97 Boeing cargo aircraft, flown November 15, 1944, was designed around the B-29 technology and hardware. A double-lobe fuselage was developed where the lower lobe was the same diameter as the B-29 fuselage while the C-97 showed a different appearance from the fuselage point of view, its wing and tail were those of the B-29. This XC-97 was the forerunner to the Model 377 Stratocruiser Series which was a commercial development of the military C-97. It was interesting to note that the first Boeing released artist's drawing

of the Stratocruiser was nothing more than an XC-97 photo. The fuselage, tail and wing were the exact transfers from the military version. This example is one where bits and pieces of hardware were transferred as well as the engine. One exception was the interior furnishings which had to comply with the airline requirements.

In the United States, the Jet Age of commercial airliners began in 1954 with the Model 367-80. Of course this was preceded by the first flight of the Comet in 1949 and the U. S. Air Force Chase G-20 Assault Glider, with B-47 in-board jet pods installed, in 1951, later redesignated as the XC-123A. The predecessors to the Model 367-80 and the 707 Series were the B-47, XB-55 and the B-52. The design of these aircraft, as the first venture into large swept wing technology, was significant. There were anticipated problems associated with high aspect ratio, high aeroelasticity, with the problem of flutter, particularly transonic flutter, the takeoff and landing problem, and the use of engine pods attached to wings. It is interesting to note that the British designed Comet incorporated internal engine installations and a clean wing, while the United States was designing aircraft with pylons and engine nacelles. As it turned out a clean wing had to have aerodynamic fences to control spanwise flow in order to achieve a docile stall, while the wings with pylons achieved the docile stall without fences.

In the development of the Boeing 707, the transfer of technology from the military version to the commercial version was more than 90% and the transfer of engine hardware such as the use of Pratt & Whitney JT-3Cs and JT-3Ds was a direct application.

In the development of the Douglas jet transport, the DC-8, much was learned from the Navy A-3D, A-4D and the Air Force B-66. The major experience gained was the construction of large aircraft - the C-124, C-133 and later the engineering design of the XC-132. However, insofar as the Douglas jet transport series are concerned the biggest transfer of knowledge was in the area of manufacturing techniques.

As time progressed from the middle fifties to the middle sixties when the large "wide body" jet transports were designed, the military aeronautics efforts were somewhat de-emphasized while funds were being added to ballistic missiles and later the space programs. Therefore, the large "wide body" jets did not have the military predecessors and the hardware transfer was minimal.

One very important development, the CX-4 and CX-HLS paper design concepts for the C-5A, permitted Douglas, Lockheed and Boeing to establish design teams for this undertaking. These teams continued to form the backbone for the Boeing 747 and the Douglas DC-10 after

the C-5A program was awarded to Lockheed. The organization of expertise permitted one to take the first step into the design and development of large jets. The technology base transfer was significant. However, experimental development transfer and detail design, construction and production were minimal.

To be specific in assessing the transfer of technology and hardware this report covers three major areas for aircraft design and development - the air vehicle, propulsion and avionics. In the area of materials and structures for the air vehicle there was a broad technology base developed as a result of government-sponsored R&D and military aircraft system acquisition. This technology was directly applicable to commercial airlines. The efforts are in the form of military specifications for processes, materials and hardware; military handbooks for design allowables and procedures; structural design concepts applied and evaluated on combat aircraft; government developed manufacturing processes and the acquisition of specialized facilities and equipment; established test procedures and fully developed equipment; and "lessons learned."

In the propulsion area the military turbojet engines developed for the KC-135 and B-52 became the power plants used in the first jet commercial transports. This was the Pratt & Whitney J-57/JT-3C engine. With minor modification, this engine was developed for the new application 707 commercial transport. Another turbojet engine was the JT-4 developed from the J-75 military version. For the large aircraft, the DC-10-10 commercial transport is using the General Electric CF6-6 engine. The basic technology of the CF6 engine, except for the revised fan system, was the same as the TF-39 engine developed under the military program.

Finally, the assessment of the relevancy of technology and hardware transfer from military to civil transport aviation is rated according to a scale of three values: high, moderate and low. The ratings are based on assessment of the actual number of military hardware efforts and the specific technology base without which the commercial aircraft could not have been built without increasing cost and extending the schedule. Quantitatively high represents 70% or more hardware transfer; moderate represents 30% to 70% and low represents below 30%. The assessments are summarized in Tables 1 and 2.

TABLE 1

DEVELOPMENT RELEVANCY/CIVIL TRANSPORT AVIATION

	BOEING 377	BOEING 707	DOUGLAS DC-8	BOEING 747	DOUGLAS DC-10	TREND
AIR VEHICLE						↘
Configuration	HIGH	HIGH	MODERATE	MODERATE	MODERATE	
Structures	HIGH	MODERATE	MODERATE	LOW	LOW	
Flight Control	HIGH	HIGH	MODERATE	MODERATE	MODERATE	
PROPULSION						↘
Basic Design	HIGH	HIGH	HIGH	HIGH	HIGH	
Total Engine	HIGH	HIGH	HIGH	LOW	MODERATE	
AVIONICS						↘
Communications	HIGH	MODERATE	MODERATE	LOW	LOW	
Navigation	HIGH	MODERATE	MODERATE	MODERATE	LOW	

TABLE 2

DEVELOPMENT RELEVANCY/CIVIL TRANSPORT AVIATION

	H S T		A S S T	
	RELEVANCY	TREND	RELEVANCY	TREND
AIR VEHICLE		→		↘
Configuration	MODERATE		LOW	
Structures	HIGH		LOW	
Flight Control	HIGH		HIGH	
PROPULSION		→		↘
Basic Design	HIGH		HIGH	
Total Engine	HIGH		LOW	
AVIONICS		→		↘
Communications	MODERATE		MODERATE	
Navigation	MODERATE		MODERATE	

SECTION II

COMMERCIAL AIRLINERS - CASE STUDIES

A. BOEING 707 - CASE STUDY

1. INTRODUCTION

The 707 was a derivative of the KC-135 which was a direct descendant of the Boeing Model 367-80 which evolved from the B-47, XB-55 and B-52 programs. The successful development of the B-47 - a high aspect ratio, highly aeroelastic, 35 degree swept wing airplane proved the feasibility of designing large, high speed commercial jet aircraft.

The B-47 was a predecessor to the -80 and in turn the Air Force KC-135 and the commercial Boeing 707. Whereas, the transfer of military hardware to the 707 was effected in the JT-3C (J-57 military designation) engine, the relevancy of the earlier military airplanes to the 707 was very high.

2. TECHNOLOGICAL ADVANCES INCORPORATED

The 707 was the first large jet commercial aircraft designed for high subsonic cruise speeds (Mach 0.8). The Pratt & Whitney J-57 engine had been proven on the B-52 and C-135 programs and its commercial derivative, the JT-3C was available for use. The high aspect ratio, 35 degree swept wing on the B-47 provided Boeing with the extensive aerodynamic and structural design data they needed to design a high performance commercial jet transport. High speeds and high cruise altitudes were essential to obtain the peak cruise mile per pound of fuel from the turbojet engine. The flight experience on the B-47 wing with pylon suspended engine nacelles was of vital importance to the 707. The B-47 flight data produced new information on the effects of structural flexibility on aileron effectiveness and handling qualities and emphasized the importance of aeroelasticity. Based on the B-47 flight results, new improved design methods were developed.

The 707 wing was an advancement over that of the B-47. It had increased thickness near the root which improved its structural efficiency and reduced its weight. Wind tunnel tests on the B-52 wing accomplished at Boeing provided extensive aerodynamic information on the effects of increased root thickness on lift and drag divergence. These tests also provided valuable new information on engine nacelle placement and pylon design which supplemented earlier tests on the B-47 nacelles. These tests provided needed design data to minimize interference drag between the wing and nacelles. Boeing found that the stall and stability characteristics of the swept wing were improved

by the pylons because they acted like wing fences and helped prevent spanwise flow which usually causes flow separation at moderate angles of attack on a clean swept wing.

The 707 design benefited from the operational experience of the B-47 in the areas of structural response, load distribution, transfer functions, fatigue and fatigue testing. In addition, the KC-135 program provided unique data and valuable experience with transonic flutter prevention and fuselage pressure testing.

From the flight control viewpoint, the 707 aircraft derives from the experiences of the B-47 and B-52 bomber programs. The B-47 with its swept wing, suffered the characteristic Dutch roll oscillation and applied an electronic yaw damper as a fix. The aeroelastic distortion of that wing under loads caused the loss of aileron effectiveness to the point of control reversal. This problem limited the aircraft to speeds at which adequate control remained. The control actuation was accomplished by hydraulics which involved a transfer of technology from high performance fighters, a concept which was still troublesome in the B-47.

The B-52 used inboard ailerons to avoid wing torsional deformation. Spoilers were added as additional roll control devices. To avoid the hydraulics problems, manual control was used where possible. Since the elevator was unpowered and had limited authority, an all movable, powered, horizontal stabilizer was used for trim which provided, probably as its most significant contribution, an ability to operate efficiently over large ranges of center of gravity position. A yaw damper, functioning purely mechanically and using a weight and a magnetic damping device, met the criteria of simplicity and avoided hydraulics problems, but, was not sufficiently effective in its intended function.

The J-57/JT-3 engine was the first production engine employing the dual spool concept. This made it possible to apply a higher compression ratio, 11.5:1, than other engines of the period. The higher efficiency of the cycle and the engine components produced a 20% reduction in fuel consumption compared with single spool, low pressure ratio turbojets. The extensive use of titanium in the rotors and static structure increased thrust-to-weight more than 10%. The J-57 and JT-3 engines had a high degree of commonality when the commercial engines were introduced to service. The military program preceded the start of the commercial program by a number of years and up-rated models were being developed concurrently with the commercial program. The military experience generated was readily applied to both programs.

The military engine program developed manufacturing technology that was applied directly to the commercial engine. The problem

of hydrogen embrittlement associated with the early application of titanium to rotating and static parts was solved. Minute amounts of contamination obtained during processing and fabrication produced brittleness and had to be eliminated by new procedures. New high temperature alloys and coatings were developed to improve the life of the turbine parts operating at higher temperatures. These examples of problems were solved prior to commercial application.

The avionics functions for the 707 were derived from the KC-135 and B-52. The military oriented electronics was replaced by commercial equipment and passenger address systems and entertainment systems were added.

The electronics systems techniques, were in a large degree derived from the military. For example, the Distance Measuring Equipment (DME) and Air Traffic Control (ATC) were derived from Tactical Air Navigation (TACAN) and Identification, Friend or Foe (IFF). The C-Band altimeter equipment and antennas were directly obtained from the military. The phased array weather radar antenna, the Omega systems, the Loran systems, the Instrument Landing System (ILS), the microphones and both radio and radar altimeters were all derived from the military. Examples were development of High Frequency (HF) antennas by scale modeling techniques using VHF Omnirange/Line of Communications (VOR/LOC) antenna impedance matching network and development of Low Frequency/Automatic Direction Finder (LF/ADF) antenna.

3. VEHICLE HARDWARE (TRANSFER)

a. AIR VEHICLE

The vehicle configuration and design of the Model 367-80 served as design "know-how" for the initiation of the Air Force KC-135 and the commercial model 707 programs. While the latter two aircraft were under construction, the -80 continued to serve as a "guinea pig" for aerodynamic features, handling qualities and new equipment. The basic 707 configuration was almost a direct transfer from the B-47 bomber aircraft. However, changes in the 707 configuration were made to adapt it to commercial use. These changes were: low wing, a thicker root section, and an improved landing gear configuration. The 707 made use of yaw dampers, similar to the B-47, to improve low speed flying qualities.

The direct transfer of major air vehicle parts and components from the B-47 to the 707 did not take place. However, the technology transfer from the B-47, XB-55 and B-52 was high. It is recalled, however, that the Air Force re irement called for an aircraft of the C-135 type previous to the itiation of a 707 design. Consequently, there is a high degree of commonality between the two airplanes.

Much of the 707 structure is similar to that of the KC-135 with the notable exception of the fuselage design, the use of the 2024 aluminum alloy and improved joint design in the lower wing skins for longer fatigue life.

In developing the 707, as well as the military KC-135, Boeing attempted to apply all of the lessons learned in the B-47 and B-52. For example, the use of spoilers for roll control and the provision of inboard ailerons came from the B-52. In addition, the problem of the mechanical yaw damper, as experienced on the early military jets, was avoided by using a hydraulically-powered electronic yaw damper. The latter, in turn, was transferred back into the late B-52s. The rudder surface was divided and one of the segments was actuated by this yaw damper.

The autopilot for the 707 was a Bendix design, derived directly from prior military experience.

b. PROPULSION

The 707-120 engine, JT-3C, develops approximately 12,000 pounds thrust for takeoff at sea level. This twin-spool, high pressure ratio engine was derived directly from the military J-57 engine developed for the B-52. The Boeing 707-120 made its first commercial flight on October 28, 1958, more than six years after the first flight of the B-52. Development of the military J-57 engine was started in 1949. Prior to the first commercial flight, more than 68,000 hours of engine development testing were completed. Military airplanes had completed more than three million engine flight hours. The military experience was of direct benefit to the commercial engine because of the similarity. Approximately 400 million dollars were spent by the military on J-57 development by 1956.

The major tooling provided for military engine manufacture was directly applicable to the commercial engines. The test facilities for development, which represent a major capital investment, were used in the commercial program without modification. For this program, Pratt & Whitney built the Willgoos Laboratory, the first privately-owned altitude test facility capable of testing complete engines and major components at all conditions within the flight envelope.

c. AVIONICS

Boeing procured their electronic systems direct from commercial vendors. However, the vendors used basic military avionics equipment designs to produce the equipment. The cost savings were considerable since the vendor did not have to requalify his product

to military requirements. The electronic systems were procured by Boeing to their specifications requiring the vendor to supply systems certified by FAA.

A small percentage of electronic hardware was transferred from the military directly to the 707, however, the techniques and applications of electronics can be traced directly to the B-47, B-52 programs. Inertial platforms, automatic pilot control, antenna applications were directly derived from military. The hardware transfer relevancy is considered to be moderate.

The communications radio systems were vendor supplied in accordance with requirements specified by the airframe manufacturer. The airframe contractor specifications required that all vendor produced communications systems be FAA certified in accordance with the applicable Aeronautical Radio Inc. (ARINC) characteristics. An example of this is the VHF-AM radio set which had to be certified to ARINC Characteristic 520. The commercial vendor items were derived from earlier requirements of military B-47 and B-52. The transfer of communications hardware was moderate.

Less than 50% of the items of navigation systems in the 707 have been derived directly from the military. The Sperry Autopilot and Litton Inertial Navigation Systems were direct carryovers from the military. As with communications systems, the contract required that the major navigation systems be certified by FAA to ARINC standards covering that system. Examples of this are the Collins Radio Compass 51Y-3 certified to ARINC Characteristic 530 and the Wilcox ATC Transponder certified to ARINC Characteristic 532.

Considerable electronics are used in areas other than communications and navigation. Examples of these are Selective Calling Systems (SELCAL), Automatic Pilot Control, Stability Augmentation System and Data Systems Recorders as well as a multiplicity of computers. Examination of these systems reveals also that less than 30% was transferred directly from the military. Again the contractor prepared specifications for these items required FAA certification. An example of military transferred system above is the Sperry produced Automatic Pilot Control.

4. GENERAL DISCUSSION

This airplane is an excellent example of a "quantum jump" made possible by military technology and, also, of the mutually beneficial exchange between commercial and military aircraft 707/KC-135.

As noted previously, the technology base for the 707 was generated by the contractor's B-47, XB-55 and B-52 programs and

refined by the prototype 367-80 and the KC-135. The 707 benefited from the KC-135 flight and structural test programs and from its manufacturing technology and facilities while the KC-135 benefits from the 707 due to the higher airline utilization rate.

The experience with the propulsion system is generally similar to the airframe in that the prototype 367-80 powered by a military engine, J-57, from which the commercial JT-3C was derived. Here again, considerable experience was gained with the military version for which manufacturing and test facilities developed and shared with the commercial product.

The relevancy of military development to the design of the 707 is as follows:

AIR VEHICLE	
Configuration	High
Structures	Moderate
Flight Control	High
PROPULSION	
Basic Design	High
Total Engine	High
AVIONICS	
Communications	Moderate
Navigation	Moderate

B. DOUGLAS DC-8 - CASE STUDY

1. INTRODUCTION

In the 1940s Douglas was deep in development and production of military aircraft. However, at Long Beach, Douglas continued to design and build transport aircraft following the lineage of the DC-4s. The DC-4 lineage led to the B-19, a very large 212 foot span airplane, then to the C-74, C-124 and C-133. The C-133 aircraft had a gross weight of 255,000 pounds and was one of the heavyweight cargo haulers designed for the Air Force. At that time studies were being undertaken to develop even larger cargo aircraft and the XC-132 military air transport development was announced in 1955. This gas turbine propeller aircraft was never built; however, it set the stage for 400,000 pound airplanes. At that time, Douglas assembled a design team to enter the USAF tanker competition. This same team initiated the design and development of the famed DC-8 aircraft. By that time, the United Kingdom was already flying the Comet and Boeing had built their Model 367-80, the forerunner for the 707 and the KC-135.

For background, Douglas had already built high subsonic speed aircraft such as the Navy A-3D, A-4D and the Air Force B-66. These aircraft provided some of the technology know-how for a large high subsonic speed commercial transport. This undertaking had to be accomplished in as short a time as possible because competition was high. On this basis, Douglas undertook the program without a predecessor or a prototype. Just as other transports had done for propulsion, the Pratt & Whitney JT-3C was incorporated in this aircraft as a direct hardware transfer from military application.

The configuration of the DC-8 was fairly conventional. An improved airfoil was designed by Douglas, utilizing data derived from NACA and military R&D programs which permitted five degrees less sweepback than the 707. The airplane was manufactured and assembled at Long Beach utilizing Air Force plants, and, two new assembly buildings especially constructed by Douglas for the DC-8. This aircraft proved to be an outstanding commercial transport and was later modified to the Super DC-8 which is one of the largest transports in use other than the "wide body" jets.

2. TECHNOLOGICAL ADVANCES INCORPORATED

The primary technological advances for the DC-8 were the advanced airfoil design, efficient structure, and improved stability augmentation and handling qualities and thrust reversers. This aircraft was one of the first to incorporate thrust reversers which would be used for landing and also in-flight. Many new manufacturing techniques were employed in the DC-8 including the use of brazed

hydraulic fittings to minimize hydraulic leakage problems and to improve maintenance.

The design and development of this aircraft utilized the procedures and some of the equipment acquired for the structural static and fatigue tests of the A-3D, B-66 and C-133, for proof testing and component fatigue testing.

An airload survey based on military requirements and prior experience was conducted to validate the airloads used in the design.

The FAA Bird Strike Test Facility at Atlantic City was utilized to certify the windshields for bird strikes.

The J-75/JT-4 was basically a 1 1/2 scaled-up version of the J-57/JT-3 engine. The thrust-to-weight ratio was improved by reducing the structure weight. Installation efficiency was improved by increasing the airflow per unit of frontal area.

The J-75 and JT-4 differed in some respects as a result of application of new commercial regulations and flight experience from the JT-3. However, there was still a high degree of commonality when service started. The simultaneous portions of military and commercial development programs effectively complemented each other.

The DC-8 aerodynamic design was strongly influenced by the competition of the 707 which threatened to take over the commercial market. Since Douglas did not choose to develop a prototype they used a conservative approach in many areas. The 35 degree swept wing on the B-47 had demonstrated that high lift-drag ratios and good stability could be achieved at high subsonic Mach numbers. This advancement led the way and proved that large jet commercial aircraft were feasible. Douglas established a design goal for the DC-8 to have the same cruise Mach number as the 707 and have better low speed stability and control characteristics. After considerable study and analysis, they decided to reduce the wing sweep to 30 degrees and increase the root thickness ratio compared to the B-47 wing. Starting with the C-74, Douglas had been investigating improved airfoil sections for high speed flight and this gave them confidence that they could reduce the wing sweep and increase the root thickness while retaining the same cruise Mach number as the 707. Although some argument still exists on the relative cruise speeds of the DC-8 and 707, Douglas essentially achieved their design goals for the DC-8 wing.

3. VEHICLE HARDWARE (TRANSFER)

a. AIR VEHICLE

The DC-8 configuration was developed around the extensive design data Douglas compiled from their military and commercial aircraft development and independent research programs. The knowledge they had accumulated on the aerodynamic design of airfoils, wings, fuselages, tail surfaces and high lift devices was infused into the DC-8.

Wing Airfoil Section. High application from Douglas research programs.

Wing Geometry. Moderate application from earlier high aspect ratio swept wing aircraft such as the B-47, B-52 and B-66.

Trailing Edge Flaps. Double-slotted flap design was based on extensive design data and wind tunnel tests from the XC-132, C-133 and DC-6. There was high application from these earlier developments.

Wing Spoilers. Moderate application of design work accomplished on the A-3D Program.

Fuselage. Moderate application of design data from the DC-4, C-54, C-74 and DC-6 aircraft.

Control Surfaces. Moderate application of design data obtained on aerodynamic controls, trim tabs and aerodynamic balances starting with the C-74 Program.

Some specific structural design concepts, material processing and treatment procedures adapted to the DC-8 design are:

- Fiberglass isolation bands (B-66)
- Fiberglass panel sealing (B-52)
- Horizontal tail pivot (A-3D)
- Formed stringers/tapered skins (A-3D)
- Pylon mounted engines (A-3D)
- Chem-milling

The design and development of the DC-8 utilized the procedures and some of the equipment acquired for the structural static and fatigue tests of prior military programs, the A-3D, B-66 and C-133. An airload survey based on military requirements and prior experience was conducted to validate the airloads used in the design. Also, the Government provided the Numerically Controlled Tooling that was employed in manufacturing the aircraft.

The control system of the DC-8 made maximum use of established technology. The primary controls were mechanical with hydraulic actuation being used only where manual power was insufficient, and then with provisions for manual reversion in case of hydraulic failure. All mechanical and hydraulic components were designed in-house. The auto-pilot was furnished by Sperry and used accelerometers as the basic stabilization sensors. This was sound in principle but, like all new approaches, required about three years to reach a satisfactory state of service. The problems of rate gyros were avoided by this concept, but the electronics state of the art required by this embodiment was inadequate at that time. Hydraulic leaks and high surge pressure problems that occurred were successfully solved. Douglas engineers estimated that about 50 percent of the technology used came from military sources - primarily its own experience with the B-66, X-3 and A-3D aircraft.

b. PROPULSION

The first Douglas DC-8 incorporated the Pratt & Whitney JT-3C engine, a direct application of the military J-57. As aircraft weight increased, more thrust was needed and later versions of the DC-8 began to incorporate the Pratt & Whitney JT-4 which was derived from the military J-75 engine.

The McDonnell Douglas DC-8-20 transport is equipped with four JT-4 turbojet engines which develop approximately 16,000 pounds of thrust for takeoff. It cruises at 0.8 Mach number at about 35,000 ft altitude. The DC-8-20 transport completed its first commercial flight on March 6, 1960, eight years after the start of development of the military J-75 (1952). More than 32,000 hours of engine development testing and approximately 15,000 hours of flight in military aircraft were completed prior to the first commercial flight. The military experience coupled with the technology transferred from the J-57/JT-3 program directly benefited the commercial JT-4 program. Government expenditures for the J-75 engine were approximately 220 million dollars by 1956. The design requirements and criteria for this engine reflected the experience gained in the commercial operation of the JT-3 engines and newly applied FAA regulations, in addition to the military engine program. This resulted in minor design differences from its military counterpart such as disc rotor burst strength and noise.

The manufacturing technology developed in the J-57/JT-3 program was applied to this new program without major modification. The achievement of high thrust-to-weight was possible through application of new lightweight structures and increased airflow per unit of frontal area. Specific fuel consumption was comparable to the J-57/JT-3 engine.

The majority of the major tooling required for the engine was provided jointly and used to produce both engines. Modification of the J-57/JT-3 test facilities to increase airflow capacity was necessary for both sea level and altitude testing.

c. AVIONICS

About 60% of the avionics hardware incorporated into the DC-8 derived from commercial companies. Douglas prepared specifications based on ARINC characteristics to cover the particular equipment being purchased. All avionics systems are FAA certified. Examples of these systems are: VHF/AM, Collins 17L-7 transmitter and 51X-2 receiver certified to ARINC Characteristic 520. Radio Compass, Collins 51Y-3 certified to ARINC Characteristic 530, Glide Slope, Collins 51V-3 certified to ARINC 519 and Marker Beacon, Collins 51Z-2 or Bendix MKA-7A certified to ARINC characteristic 519. The electronics equipment directly transferred was the AN/CRT-3 rescue radio transmitter and the SCR-718 High Altitude Altimeter.

4. GENERAL DISCUSSION

As with most designers, Douglas initiated a study of the potential of jet transports in 1947. By 1951, they had concluded that the turbine-jet powered airplane offered a greater potential than the turbine-prop powered airplane. However, the decision to proceed with a design was delayed at this time because of the status of engine development, financing and a lack of interest by the airlines.

When the decision was finally made to proceed with the DC-8 design, the prototype of the 707 had already flown. In order to be competitive, Douglas chose to forego a prototype development phase for final product design development, but to proceed immediately with a design configuration which would have the same cruise Mach number as the 707 but which would have better low speed stability and control.

In the design of the airframe, the use of proven materials at relatively low stress levels with specific attention to details and the application of automated machinery, including automatic riveting, in the manufacture has resulted in a basic airframe with high reliability and low maintenance.

The rather extensive flight and ground testing which was performed on this airplane had, as its basis, the extensive experience this contractor had accumulated with military aircraft. In fact, some of the equipment utilized in military testing was acquired for the DC-8 program.

While there was no direct transfer of airframe or equipment from military aircraft to his airplane, the basic design was predicated on data developed by military research, development and operational programs modified to commercial requirements. Transmission of much of the design data was made by means of military specifications, handbooks and technical reports.

Manufacture of the airplane was performed at the Long Beach Facility, a defense plant facility constructed for the manufacture of B-17s, which was supplemented by the construction of two new assembly facilities by the contractor.

The relevancy of military development to the design of the DC-8 is as follows:

AIR VEHICLE	
Configuration	Moderate
Structures	Moderate
Flight Control	Moderate
PROPULSION	
Basic Design	High
Total Engine	High
AVIONICS	
Communications	Moderate
Navigation	Moderate

C. BOEING 747 - CASE STUDY

1. INTRODUCTION

The introduction of jet powered commercial transports resulted in a major expansion of the worldwide air transportation system during the 1960s. By the mid-60s it was clear that larger and more efficient aircraft would be needed if the industry was to continue to grow in an orderly manner. The key to large, efficient new transports was an advanced propulsion system, and the high bypass engine developed by the Air Force offered an ideal solution to this need.

The Boeing 747 development proceeded from the large background of design data obtained on the KC-135, 707, 727 and other Boeing programs. The same design team that had been drawn together to work on the C-5A proposal formed the backbone for continuation of large commercial transport concepts. The extensive analyses and wind tunnel testing on the C-5A proposal aircraft undoubtedly contributed significant preliminary design information for the 747 although the final configuration was different from the proposal aircraft.

2. TECHNOLOGICAL ADVANCES INCORPORATED

The 747 aerodynamic design made effective use of an improved "peaky" airfoil design which provided good lift characteristics at high subsonic speeds. This section significantly improved the buffet boundary compared to the 707 aircraft. Extensive wind tunnel testing was accomplished for the 747, by Boeing, before the first flight - about 15,000 hours. By the end of 1971 this figure had risen to about 20,000 hours. A triple slotted flap was developed for the 747 which had its background in the development of the 727. Boeing made extensive use of ground base simulators to verify the flight handling qualities and stability and control. This procedure combined with the extensive aerodynamic testing in the wind tunnel contributed to the rapid development of the final configuration and the early solution of problem areas.

The 747 airframe made extensive use of fiberglass panels and components in many areas to reduce the weight. This was a step forward in structure design. The use of titanium in the wing landing gear beam, first in the form of extrusions and finally as forgings, represents a significant advance in structural efficiency.

The control system of the 747 is several-fold more extensive than the systems employed in the 707. The control surfaces are all fully powered - no "manual" control is possible. Four independent hydraulic systems are employed. The control surfaces themselves

are divided so that the redundancy extends to the aerodynamic surfaces. The redundancy is so extensive that no loss of any control performance results from a single failure, and even a second similar failure does not cause unacceptable control (this is known as a "fail-operate, fail-soft" control system). The electronics elements, those things known as the autopilot and stability augmentation system, are directly integrated with the hydraulics actuation components as contrasted with past practice of employing electro-mechanical servomechanisms driving through the pilot's input to the hydraulic actuation. A high level of redundancy exists in the electronics so that operation after a single failure is not degraded. Sophisticated guidance and automatic landing, features of both this aircraft and the DC-10, cannot tolerate failures or several control transients in such critical maneuvers as landing. Thus, it may be seen that the control-to-aircraft interactions are more critical and the performance requirements are more demanding for all of the current "wide body" transports. (Provisions for growth of functions such as full landing under Category III conditions and possible new traffic procedures have been considered and accounted for by all of these designs.) A further factor which influences these control designs is the growing realization that the pilot's abilities and limitations are a key element of control. The 747 control system provides a flight director system which derives its signals from the same signal sources and computers as the automatic control. The pilot may easily monitor the automatic operation, may exercise control in conjunction with the automatic, or may assume the total guidance and control function without loss of orientation and with full understanding of the situation and without switching or control transients. Simplification of operating controls and status monitoring has been widely practiced.

Boeing first employed these piloting and instrumentation features in various degrees in the 727 and 737 aircraft, not under consideration here. These applications served as prototypes and added confidence to the 747 development.

Additional technology benefit accrued from hydraulics experience in these aircraft which were more modern than the 707 designs. An interesting note on hydraulics expertise was made by a Boeing engineer. He stated that the hydraulics authority for these aircraft was an engineer who had had more than twenty years experience and had retired from another company, a company which had produced a succession of high performance military systems.

The features catering to the pilot's abilities and which allow him to exert his control intention most naturally were originated from in-house experimental flight research by the Air Force and validated inflight by a broad spectrum of pilots, including representative pilots of U. S. and international air carriers.

3. VEHICLE HARDWARE (TRANSFER)

a. AIR VEHICLE

The structural design of the 747 drew heavily upon the engineering background and technology base assembled by Boeing in designing and developing many large military and commercial aircraft. Their independent R&D programs, particularly in the areas of power spectral density (PSD) gust design procedures, runway roughness measurements for dynamic taxi loads, fatigue and fracture, and materials applications, made significant contributions to the 747 development.

From Boeing discussions and independent knowledge of Air Force and vendor programs, it is concluded that the origin of the control technology for the 747, including the control configuration and pilot features, derives directly or through other Boeing systems from military sources to about 50%. The direct application of hardware is minor.

b. PROPULSION

The 747 engine, the Pratt & Whitney JT-9D, was a major advance in turbine engine design. It used an extremely compact, lightweight structural approach which featured a twin rotor system supported on four bearings with modular component design. The elimination of conventional inlet guide vanes and the low primary jet velocity resulting from the high bypass cycle gave the JT-9D substantially better noise characteristics compared with contemporary engines. The development of high temperature air-cooled turbines was also a major development achievement of this engine. Many of the technical advances incorporated in the JT-9D program had government support. A joint military/industry research and development program was begun during the early 1960s with the aim of improving the general turbine engine technology base. The Lightweight Gas Generator Program explored high performance, compact compressors and high temperature turbine design. Technology for this program was incorporated by Pratt & Whitney in a very advanced full-scale demonstrator engine designated the STF-200. This engine became the prototype for a new generation of high bypass ratio engines. Two major demonstrator engines evolved from the STF-200. One, the Pratt & Whitney JTF-17, was a competitor for the United States Supersonic Transport Program and the other, the Pratt & Whitney JTF-14, competed for the Air Force C-5A transport program and, although not selected for this application, was redesigned as the JT-9D which was chosen to power the Boeing 747. The JT-9D development began in January 1966 and the 747 first flew in commercial service four years later in January 1970. At that time approximately 5,000 hours of engine

development testing had been completed by Pratt & Whitney. Lacking a military counterpart, the opportunity to discover and correct any design problems before commercial use was not present. During the second year of operation, the engine experienced a 0.35/1000 hours inflight shutdown rate with the total flying time of 2,458,343 hours since entering commercial service. Also, during this second year of operation, the engine experienced an unscheduled removal rate of 0.94/1000 hours.

c. AVIONICS

All of the avionics equipment incorporated into the 747 is commercially produced. The equipment must be designed to applicable ARINC characteristics in order to be certified by FAA.

The production types for commercial airliner use, however, will have vendor supplied items as used in previous commercial aircraft. The technology base for the vendor produced items in the aircraft examined for this study has a certain percentage directly contributable to military. For example, the component parts in practically all of the vendor items are supplied to the vendor designed to Military Standards. In addition, the methods and techniques used in antenna development, antenna impedance matching, station keeping, Omega and Loran Systems, Microwave ILS, lightning protection systems, Heads-Up Displays, Multipurpose Displays (CRTs), Warning Systems and integrated instruments and lighting were military derived.

In the communication hardware the transfer of hardware items from the military was low. The communication radio systems are vendor supplied in accordance with requirements specified by the airframe manufacturer. The airframe contractor specifications require that all vendor produced communications systems be FAA certified in accordance with the applicable ARINC characteristics. An example of this is the VHF-AM radio set which must be certified to ARINC Characteristic 520.

The inertial navigation for long range flight of commercial jets was installed during the late 1960s. The 707-300s, Super DC-8 and others began to employ Litton systems. The 747 uses three Inertial Navigation Systems (INS) built by A C Electronics to ARINC specifications. The hardware transfer was moderate.

4. GENERAL DISCUSSION

The present generation of commercial jet transports represents an evolution from the military B-47 and B-52. From these military programs and the conceptual phase analysis and R&D leading to the C-5A transport came the impetus for the "wide body" jets.

Hardware transfer from the military programs to the 747 commercial transport was low. The configuration was designed to meet commercial requirements; however, in producing the aircraft large titanium forgings are being made by Wyman-Gordon with military tooling (the 50,000 ton presses).

The plant facilities for the construction and assembly of the 747 were built by Boeing at a new site, now called the Everett Plant. The first flight tests of the aircraft were accomplished wit' Boeing and military facilities. In addition to Boeing Field and Pa ne Field, Edwards Air Force Base, Roswell AFB and Moses Lake were use.

The total test program for an aircraft of the Boeing 7' type is enormous, as shown below:

Static Test	$ 20,000,000
Fatigue Test	28,630,000
Partial Fuselage Tests	10,200,000
Development Tests	77,343,118
Flight Tests	67,701,910
Total Test Program	$213,875,018

Includes direct cost plus overhead.

The relevancy of military development to the design of this aircraft is as follows:

AIR VEHICLE	
Configuration	Moderate
Structures	Low
Flight Control	Moderate
PROPULSION	
Basic Design	High
Total Engine	Low
AVIONICS	
Communications	Low
Navigation	Moderate

D. DOUGLAS DC-10 - CASE STUDY

1. INTRODUCTION

The McDonnell Douglas DC-10 Medium Range Transport airplane was designed as a 413,000 pound aircraft to transport 270 passengers and 2,240 cubic feet of containerized cargo at a speed of Mach 0.88 between 34,000 and 42,000 foot altitudes for about 3,000 nautical miles. The airplane has a 35 degree swept, fixed wing and is equipped with three General Electric CF6/36-6 turbofan engines, two enclosed in pylon mounted nacelles beneath the wing and one mounted at the base of the tail fin.

The DC-10 was developed around conservative design goals and criteria to minimize risks and shorten development time. The aircraft was designed to take advantage of the fuel economy and thrust characteristics of the high bypass ratio turbofan engine. The GE CF6-6 engine, used in the DC-10, has already achieved an outstanding record of reliability and dependability.

2. TECHNOLOGICAL ADVANCES INCORPORATED

McDonnell Douglas designed the DC-10 wing with a "peaky" airfoil section which provides good lift capability at high cruise speeds while reducing shock wave losses and flow separation. The design work McDonnell Douglas did in support of their C-5 proposal to the Air Force, made a major contribution to this improved airfoil section. The C-5 proposal wind tunnel tests also contributed new design information on nacelle and pylon drag increments. The DC-10 wing design has 35 degrees of sweep and tapers in thickness ratio. The main wing spar has a compound curvature near the root section which permits an optimum variation of thickness ratio in the inboard region of the wing. This advance in structural design technique contributed to the good cruise drag characteristics at high Mach numbers. The DC-10 has double-slotted wing flaps of similar design to the DC-8 and earlier Douglas aircraft. This basic flap design goes back to the development of the XC-132 and C-133. Douglas conducted many two- and three-dimensional wind tunnel tests on the double-slotted flap and now have a large design data bank on this type of flap system. They optimized the aerodynamics of this flap through their work on many military aircraft and the DC-8, DC-9 series. The leading edge slat used on the DC-10 is similar in design to the DC-9 slat. Here again, the design experience gained by Douglas on many military programs, particularly fighter aircraft, greatly contributed to the leading slat design used on the DC-9 and DC-10.

The straight inlet and diffuser of the tail engine on the DC-10 was an improvement in aerodynamic design. This avoided the

flow separation problems associated with the "S" curve diffuser on other tail engine installations and resulted in a definite improvement in specific fuel consumption because of lower inlet flow distortion. The SFC of the tail engine is only 1/2 percent higher than the wing mounted engines under both cruise and climb flight conditions. This improvement required a larger, complex structural frame to hold the engine and take the tail loads.

The nacelle strakes on the DC-10 improve the maximum lift on the wing by preventing flow separation in the region inboard of the wing mounted nacelle. These aerodynamic devices generate a powerful vortex which sweeps high energy air above the wing down into the boundary layer and reduces the flow separation at high angles of attack. This device was first investigated by Douglas in their work on the XC-132. Although it was not very effective on the XC-132 it was thoroughly investigated in the DC-10 wind tunnel tests and found to give good results. It was eventually incorporated on the DC-10 when early flight tests disclosed an early flow separation on the wing near the nacelles. The strakes were found to be quite effective and eliminated the problem.

The DC-10 aerodynamic team had established firm design goals and used the wind tunnel quite extensively to investigate potential problem areas and design changes which could be easily made on the flight test airplane. They recognized four risk areas and incorporated means in the aircraft to make slight adjustments during the flight tests. These areas were:

Spoiler Response. Different cams were designed to change the gearing ratio to achieve near constant roll response at various speeds.

Nacelle Strakes. Designed from wind tunnel tests to improve the wing maximum lift. Not used on first flight, but were incorporated early in the test program.

Slat Rigging. The slats were made readily adjustable on the flight test aircraft to optimize deflection angles and slat gaps.

Elevator Stick Force. Provisions were incorporated in the control system to make it possible to adjust the elevator stick forces and optimize handling qualities. These design features enabled McDonnell Douglas to quickly make changes in the flight test aircraft which contributed to the rapid development of the DC-10. There is no doubt that the engineering knowledge they gained on many past military and commercial aircraft programs helped them avoid serious problems due to aerodynamic design deficiencies.

The basic technology of the CF6 engine, except for the fan system, was the same as the TF-39 engine developed under the military program. The most significant was the technology of high temperature turbine design and the high pressure compressor. The high pressure compressor was highly efficient with outstanding stall-free operation in cross-winds and adverse operating conditions. The new, efficient high bypass fan with substantially reduced noise was based on the background gained from NASA and military funded programs. The installation technology for high bypass fan engines was developed by government-funded research.

The results of government-sponsored R&D in the areas of non-stationary aerodynamics; low level turbulence measurement, definition and analysis; parametric fatigue analysis; fracture toughness; structural analysis programming and manufacturing technology were directly transferred to the DC-10 design team. In addition, operational experience with the A-3D and B-66, in particular, the cold weather sonic fatigue tests conducted in Alaska on the B-66, influenced the detail design of this aircraft.

The control system of the DC-10 is a fully powered system. Three totally independent, hydraulic systems provide ample redundancy. Mechanical and hydraulic systems were extensively studied and tested as a complete system on an "iron bird" which simulated the mechanical conditions of the full-scale aircraft and millions of cycles of operation were performed to test all possible component failure modes to guarantee integrity of control. The design approach could be classed as original with Douglas but was based on technology acquired from its own prior experience and that of others. The concept of reliability achieved through the use of redundant elements was fundamental to this design. This concept, which acknowledges that even with the minimum requirements for control, the sophistication and probable failure rate of components, even those of the best quality, require this redundancy where safety is the paramount requirement. The studies and experiments and later engineering which explored and developed these redundancy concepts were military in origin and began about 1959. The general civil transport designer's view of complex redundancy in 1959 ranged from one just short of ridicule to one which regarded any possible application as being restricted to sophisticated military weapon systems, systems totally unlike civil transports which would remain simple and intrinsically reliable. The increased sophistication of transports including such features as automatic landing demand a continuity of control, without deterioration of quality, that force the use of redundancy configurations such as the DC-10 employs.

3. VEHICLE HARDWARE (TRANSFER)

a. AIR VEHICLE

The DC-10 configuration evolved from many earlier military and commercial programs, but is essentially a new design. The Douglas aerodynamic methodology used to design the wing, tail, fuselage and nacelles was formulated and improved throughout the 1950 - 1970 time period and received contributions from many Douglas military aircraft. Although actual hardware transfer did not usually occur, strong evolutionary paths can be identified in the areas of wing and airfoil section development, double-slotted flap and leading edge slat design, fuselage shaping, tail surface location and geometry, and pylon/nacelle aerodynamic design. The work Douglas did in support of their C-5 proposal also provided new design information in many areas, for example, the advantages of the peaky airfoil section in achieving good high Mach number cruise efficiency. Their independent research and development, funded from many military programs, made major contributions to their data bank and was an important part of the technology needed to design the DC-10. There is no doubt that McDonnell Douglas also made good use of the available research information, particularly NACA wind tunnel tests.

Hardware concepts, which were government conceived or sponsored, which have been applied in the design of the structure of the DC-10 are:

- Titanium slat and flap tracks (A-3D)
- Floor structure (C-133)
- Peen forming of large skin structures (B-52)
- Local overaging technique for T6 to T73
- Cold drawn and aged titanium springs
- Brazed stainless steel hydraulic tubing
- Brazed chemically pure titanium tubing with Ti-6Al-4V fittings
- Thin wall aluminum (356) castings
- Isothermal - no draft Ti-6-6-2 forgings
- Welded and brazed acoustical panels from Inconel 718 and 316L

. Investment castings from Inconel 718

In the area of flight control the autopilot for the DC-10 provided by Bendix was a derivative of the C-133 autopilot. Although hardware was of necessity tailored to the aircraft and to the customers' required features, certainly 50% of the technology was a direct transfer. In addition to the C-133 experience, which provided Bendix with the first transistorized autopilot, Bendix's work with the B-58 hydraulics actuation system was applied to the DC-10, its first commercial hydraulic controls. Similarly, the C-141 redundant yaw damper experience served as background for the DC-10.

As a policy, Douglas exercises total detail design of all flight control systems and components where safety is remotely involved. They believe that this policy is expected and required by their commercial customers. Also they may be legally liable if accidents can be assigned to faulty design. Under these basic assumptions, hardware transfer from outside the company would be minimum.

Prior to the DC-10 program, Douglas acquired dynamic simulation facilities and know-how. The most recent acquisitions were credited to the APOLLO Program.

As a judgment, based on Douglas statements and on independent knowledge of control industry programs, approximately 30% of the technology can claim military sources. This is not insignificant when one recalls that the control system of the DC-10 is several-fold more sophisticated and costly than predecessors like the DC-8.

b. PROPULSION

The basic technology of the CF6 engine, except for the fan system, was the same as the TF-39 engine developed under the military program. The TF-39 engine contract was awarded in 1965. The DC-10/CF6 made its first commercial flight in August 1971. Prior to the first commercial flight of the DC-10/CF6, more than 30,500 hours of engine development testing were completed, 27,000 hours as a TF-39 and 3,500 hours in the CF6 configuration. Additionally, approximately 128,000 engine flight hours had been accumulated in the C-5 aircraft. Because of the similarity, the military experience was of great benefit to the CF6 commercial engine, as attested by an inflight shutdown rate of only 0.05/1000 hours after only six months airline service totaling 38,000 flight hours. During this same time period the premature, or unscheduled, removal rate was 0.21/1000 hours. The Government invested 212 million dollars for the development of the TF-39 engine. A leased B-52 was utilized as a flying test bed for the CF6 development.

c. AVIONICS

There was very little direct transfer of military avionics equipment to the DC-10. All systems are commercially produced. The majority of systems are produced by more than one company and the airplane customer often has a choice of two or more vendor items. An example is the VHF/AM communications radio set. The customer is given a choice between the Collins VHF-AM 618M-2, the Bendix VHF-AM RTA-42 or the King VHF-AM KTR-9000. These radios, as well as most avionics systems, are vendor designed to applicable ARINC characteristics.

The electronics systems techniques were in a large degree derived from the military. For example, the Delco INS Carousel navigation system was developed by the Air Force, the DME was derived from TACAN and the ATC was derived from IFF. The C-Band altimeter and antennas derived from the military. Antenna techniques and applications were military derived: for example, development of HF antennas by scale modeling techniques. The use of VOR/LOC antenna matching network and the development of LF/ADF antennas came from military programs.

The examination of the avionics equipment configuration of the Douglas DC-10-10 airplane revealed that less than 30% of the hardware items were transferred directly from the military. The communications radio systems are vendor supplied in accordance with requirements specified by the airframe manufacturer. The airframe contractor specifications require that all vendor produced communications systems be FAA certified in accordance with the applicable ARINC characteristics. An example of this is the VHF-AM radio set which must be certified to ARINC Characteristic 520.

Less than 30% of the items of navigation systems in the DC-10 have been derived directly from the military. As with communications systems the contract requires that the major navigation systems be certified by FAA to ARINC standards covering that system. Examples of this are the Collins Radio Compass 51Y-3 certified to ARINC Characteristic 530 and the Wilcox ATC Transponder certified to ARINC Characteristic 532.

Considerable electronics are used in areas other than communications and navigation. Examples of these are Selective Calling Systems (SELCAL), Automatic Pilot Control, Stability Augmentation System and Data Systems Recorders as well as a multiplicity of computers. Examination of these systems reveals that approximately 30% was transferred directly from the military. Again the contractor prepared specifications for these items required FAA certification. An example of military transferred systems above is the Sperry produced Automatic Pilot Control.

4. GENERAL DISCUSSION

The DC-10 is a well integrated design which makes good use of structural design advances to provide high aerodynamic and propulsive efficiencies.

The following presents a breakdown of the DC-10 component costs as a percentage of the total cost of the airplane:

Basic structure - wing, fuselage and tail	41.5%
Propulsion system including engines	17.1
Furnishings including lighting system	14.5
Avionics systems - communication, navigation	12.7
Flight control and guidance	5.3
AC power system	2.4
Hydraulic & auxiliary power systems	2.1
Air conditioning and pressurization system	1.9
Landing gear, wheels, tires and brakes	1.7
Misc. systems and components	.8
	100.0

The relevancy of military development to the design of this aircraft is as follows:

AIR VEHICLE	
Configuration	Moderate
Structures	Low
Flight control	Moderate
PROPULSION	
Basic Design	High
Total Engine	Moderate
AVIONICS	
Communications	Low
Navigation	Low

E. MEDIUM STOL TRANSPORT (MST) - CASE STUDY

1. INTRODUCTION

The Air Force's request for proposals (RFP), issued in January 1972, for prototype development and test of an Advanced Medium STOL Transport (AMST) (C-130 size) is oriented towards a jet STOL transport that would carry a 15 ton payload, have a radius of action of 500 nautical miles, operate in and out of unimproved 2,000 foot airstrips under hot day conditions, meet FAR-36 noise requirements, have a cargo compartment size 12 feet wide by 12 feet high by 55 feet long, and utilize either qualified engines or engines that have been preflight rated. Based on the above and previous government vehicle design studies, the size of this prototype should be very comparable to a STOL transport designed for operation in Short Haul (300-500 NM) High Density Transportation. A specific comparison between the Advanced Military STOL Transport (AMST) prototype and the commercial Medium STOL Transport cannot be made since the military prototype is only in the proposed stage and the Department of Transportation has not defined their Medium STOL Transport characteristics.

The schedule for the AMST Prototype is not firm at this time. First flight is scheduled within three years after contract award and a 12 month flight test program will follow. Another five years would be more than adequate to design, contract, test and obtain FAA certification of a STOL airliner for service in late 1980.

The Medium STOL Transport would have the following general characteristics:

Passengers	90 - 150
Gross Weight (lbs)	130,000 - 160,000
Engine Thrust (lbs)	16,000 - 25,000
Cruise Mach	0.75 to 0.85
Range (NM)	300 - 500
Runway length requirement (ft)	2,000
Noise level	Meet FAR-36 criteria
In-Service date	1980

2. TECHNOLOGICAL ADVANCES

The following significant advances sponsored by military R&D programs will provide a part of the technological base for the future Medium STOL Transport.

AIR VEHICLE

- Prototype STOL aircraft
- Cargo handling
- Advanced composites
- Fly-by-wire
- Control configured vehicle
- Lift augmentation devices

PROPULSION

- Advanced turbofan engine development for STOL operations
- Quiet engine technology
- Noise suppression techniques

AVIONICS

- Multifunction avionics to reduce number of boxes

3. VEHICLE HARDWARE (TRANSFER)

In addition to the above noted advances in the technological base, the following military-sponsored hardware development programs (previously discussed) will permit varying degrees of direct hardware transfer to a commercial Medium STOL Transport:

a. AIR VEHICLE

The Advanced Medium STOL Transport Prototype Program schedule is not firm at this time. First flight is scheduled within three years after contract award and a 12 month flight test program will follow.

The AMST prototype could be adapted to carry about 150 passengers. The high mounted wing and associated high lift devices, compatibility of the turbofan engines to the high lift devices, the flight control system, landing gear and cockpit displays could be directly adapted to the Medium STOL Transport. The know-how and experience gained from the AMST prototype program can be directly transferred.

b. PROPULSION

The DoD STOL demonstrator engine program contract award is scheduled for October 1972. This program will result in the design, fabrication and test of a demonstrator engine in the 20,000 to 25,000 pound thrust range with a bypass ratio in the range of 4 to 8:1, a thrust-to-weight of 7:1 and specific fuel consumption equivalent to the TF-39 and JT9-D engines. Engine testing is scheduled to begin in November 1973, with testing (100 to 150 hours on the demonstrator engine) completed by September 1975.

The STOL demonstrator engine will be capable of being utilized in either internally or externally blown flaps and/or mechanical flaps plus vectored thrust STOL transport aircraft. The engine will take into consideration FAR-36 noise criteria, have no visible smoke (SAE No. 15) based on the SAE ARP 1179 measurement specification and have lower pollutant emissions (carbon monoxide, unburned hydrocarbons, and oxides of nitrogen) than current turbofans.

Upon completion of the STOL demonstrator engine test follow-on activity is proposed to conduct a Prototype Preliminary Flight Rating Test by waiving all non-essential specification test requirements until Military Qualification Test (MQT). Upon completion of the prototype PFRT the engine will be acceptable as a prime propulsion system on experimental aircraft. It is estimated that 1500 to 1900 hours of engine testing and approximately 12 to 20 months will be required to complete the PFRT.

Following completion of the prototype PFRT, a formal MQT will be undertaken. The MQT will involve an additional 3,000 to 6,000 hours of engine testing and approximately 22 to 24 months to complete.

The prototype PFRT engine or the MQT engine could be directly used in the commercial medium STOL transport. However, in all probability the engine will have to be adapted (different thrust level) for the size transport defined for short haul transportation.

The DoD is a major participant in the National Microwave Landing System (MLS) Program. Modification of the aircraft flight path is being evaluated as one method for reducing the aircraft noise impact in the terminal vicinity. The modified flight path could be directly transferred.

c. AVIONICS

The future airborne avionics for short haul transportation system aircraft will be dependent upon results of development programs currently underway within DoD and other government agencies. The airborne avionics being utilized in these development programs will very probably not be directly utilized. However, the knowledge and experience gained should provide a high degree of confidence for adapting the test avionics to production configurations.

The following military hardware development programs deal with both airborne and ground based equipment. These programs have been previously discussed in detail and thus are briefly summarized below. All of these development programs should have a partial to direct transfer of airborne hardware.

The national microwave landing system development (with DoD participation) is evaluating the use of existing systems, signal format investigations and their application to user needs to help alleviate congestion of airways and terminal areas.

A development program is underway to provide an inflight monitor for the Navy automatic carrier landing system, which already employs a microwave scanning beam technique. A Traffic Management System Control and lightweight three-dimensional Ground Controlled Intercept (GCI) radar giving digital data is also under development.

For helicopter operations, the A-SCAN system under development utilizes a scanning beam of broad covering which provides for multiple approach paths. Improved Distance Measuring Equipment (DME) is also being developed. The Army automated Air Traffic Management System (ATMS) program is currently evaluating air-ground digital data link and tactical landing tasks for enroute approach, departure control and airborne subsystems.

A development program is underway to provide an inflight monitor for the Navy automatic carrier landing system which already employs a microwave scanning beam technique. In association with Air Force developments in the Air Traffic Control Radar Beacon System (ATCRBS), the Navy is developing a Traffic Management System Control and lightweight three-dimensional Ground Controlled Intercept

(GCI) radar giving digital data concerning aircraft at long range and high altitude.

The current Air Force development efforts for improving the Traffic Control Approach and Landing System (TRACALS) includes improved methods for tower display of altitude and identity information. The AN/TPN-19, Landing Control Central System, is one of the most recent development efforts associated with TRACALS.

Closely related to the previously mentioned ATMS is the Army Positioning and Navigation System (PANS) which provides for the development of a common positioning and navigation system employing LORAN position locators and airborne receivers.

In the area of communication links, the Air Force Position Locating, Reporting and Control of Tactical Aircraft (PLRACTA) System is based on a highly connective, high capacity, and jam-resistant digital communications system. The Army is currently developing the TRI-TAC system which is a digital transmission and switching system characteristic of the principal communications requirements of the future.

The current and planned military communications satellite programs and current military navigation satellite program (Navy TRANSIT System) could be directly utilized.

A joint DoT-DoD Program is evaluating competing techniques for full collision avoidance systems and simpler proximity warning devices.

4. GENERAL DISCUSSION

The study team assessed each of the areas as to the relevancy between the military R&D hardware programs and the Medium STOL Transport for use in short haul transportation. The know-how developed and the results of these military hardware programs can significantly reduce the amount of advanced development and prototype development necessary to develop and certify a medium STOL transport for short haul transportation.

The AMST prototype fuselage (shape and size), high mounted wing and associated high lift devices, the coupling of turbofan engines to the high lift devices, landing gear and cockpit displays could be readily transferable. However, past differences between the military and commercial performance characteristics have existed. Therefore, changes to the actual AMST prototype hardware can be expected so that only a moderate relevancy can be assessed.

The significant difference between military and commercial transport structures is the military desire to utilize composite materials to reduce weight. By contrast commercial users must pay greater attention to the unit costs and thus lean toward more conventional materials. The structure of the AMST prototype will probably be of conventional design and materials so there should be a high transfer.

The handling qualities and flight control subsystem arrangements should be readily transferable from the AMST prototype to the STOL transport. In the hydraulic system there is a difference between the military and commercial temperature requirements. Overall, however, there will be a high relevancy.

The DoD STOL demonstrator engine program will provide the confidence for achieving TF-39 performance in a 20,000 to 25,000 pound thrust size engine. The planned DoD PFRT and MQT programs will incorporate NASA quiet engine technology to achieve the lower noise levels being considered for commercial operation. The demonstration engine(s) could form the basis for the commercial STOL transport engine(s) development. Thus, a high relevancy of transfer is expected.

Traditionally, modifications have been made when adapting military developed engines to commercial use. These changes include improved turbine blade containment and modified engine control system to operate at most efficient cruise speed. The exact degree of relevancy will depend upon the similarity between future military and commercial requirements. However, a high relevancy is anticipated.

The airborne hardware being employed in the above described military R&D hardware programs has been selected from available hardware (rather than develop new hardware). These types of development programs usually identify areas where the airborne hardware should be modified to maximize system effectiveness. Assuming that the above described development programs will identify the need for hardware modifications and the desire will be to employ the latest state of the art hardware, a moderate relevancy is assessed.

The above reasoning listed is also applicable to the navigation area. A moderate relevancy was assessed.

In summary the relevancy of current and planned military development programs to the design of the future medium STOL transport for short haul transportation is estimated as follows:

AIR VEHICLE	
Configuration	Moderate
Structures	High
Flight Control	High
PROPULSION	
Basic Design	High
Total Engine	High
AVIONICS	
Communication	Moderate
Navigation	Moderate

The design criteria (especially handling qualities) resulting from the military AMST prototype program and the problems, manufacturing technology, tooling and testing associated with both the AMST prototype and the DoD STOL demonstrator engine cannot be specifically identified at this time. However, these results will provide a data base and very probably some direct transfers to the medium STOL transport.

The time phasing of the Advanced Medium STOL Transport Prototype Program, the Advanced STOL Engine Programs and a possible schedule for a civil STOL airliner is shown in Figure 1.

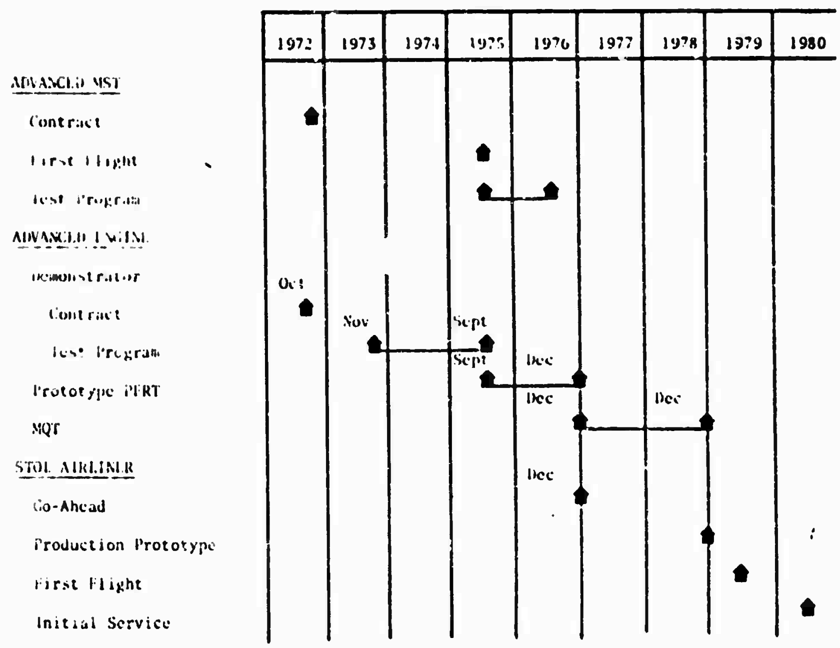

FIGURE 1

A PROPOSED MST DEVELOPMENT SCHEDULE

F. ADVANCED SUPERSONIC TRANSPORT (ASST) - CASE STUDY

1. INTRODUCTION

Growth in civil air transportation has been provided by new air vehicles representing new technology. Utilization of this new technology resulted in productivity increases through a combination of aircraft size and speed. With the projected growth of international travel in the 1980s, a need exists for an airplane which will provide an increase in productivity for that time period. This case study will evaluate the military R&D relevancy for an airplane of the 80s that will improve productivity with an increase in speed.

Previous economic studies have shown that a new air vehicle of comparable weight with today's 747 but capable of cruising at Mach = 2.7 could provide twice the productivity of the present 747.

A vehicle that would provide the productivity increase by 1983 could have the following general size, design and performance characteristics:

Passengers	250 - 300
Gross Weight (lbs)	over 500,000
Engine Thrust (lbs each)	60,000 - 70,000
Mach Number	2.7 - 3.2 above 60,000 ft
Range (NM)	4,000 - 5,000
Sonic Boom Overpressure	1.5 psi or less
Runway length requirement (ft)	12,300 or less
Titanium and composites	
In-Service Date	1985
Airframe service life (hrs)	40,000 to 60,000
Satisfy FAR-36 noise standards & environmental EPA requirements	

2. TECHNOLOGICAL ADVANCES

To meet an estimated in-service date of 1985, a configuration design freeze date would have to occur five years before or no later than 1980. The nature of the advances will have to be incorporated at freeze date in order to be of any advantage in the design. An estimated engine and airplane schedule is included later in this case study. This optimization includes improvements necessary in aerodynamics, noise reduction and pollution, engine characteristics and materials.

Incorporation of all of the presently known technological advances will have to be utilized to attain a payload-to-design gross weight ratio greater than 8%, thereby making it economically viable.

The following significant advances (previously discussed) sponsored by military R&D will provide a part of the technological base for the supersonic transport:

- Advanced Composites

- Advanced Metallic Structures
- Controlled Configured Vehicles
- Airframe/Propulsion System Integration
- Improved titanium manufacturing techniques
- Microelectronics
- ATEGG "building block" approach to engine generator design and development

3. VEHICLE HARDWARE (TRANSFER)

A schedule for engine development, airframe development, 707 milestones, and appropriate B-1 milestones are included in Figure 2 to support a 1985 in-service date.

The B-1 is one of the military aircraft developments that has relevancy to a future long haul commercial transport. The B-1 blended wing/body configuration concepts will provide further knowledge on high speed configuration design.

a. AIR VEHICLE

Variable-sweep design used on the B-1 will provide some design, construction, test and operational experience for possible use on a future ASST. Blended wing/body configuration concepts will provide further knowledge on this type of airframe improvement. The fluorosilicone fuel tank sealant was considered as a sealant for the terminated prototype SST and is now being used on the B-1. Even though the method of sealing fuel tanks would vary between B-1 and any future ASST, this basic sealant material could be considered until better material concepts are developed.

The use of boron advanced composite laminated on the longerons provides a vehicle on which this method of saving weight will be tested. This method provides a primary structural application of the material and could be used on the ASST for weight saving.

Sonic fatigue design being applied to military systems and experience gained from this effort will be useful to future ASST.

Structural mode control was planned on the prototype SST. This concept generated from the military's response to improve the structural life of the B-52. The program was initiated to improve

elastic mode control and rigid body control. Particularly, active flutter control will be applied on a future ASST. This mode control also provides some load alleviation and will assist in reducing structural weight.

Even though the B-1 operating temperatures are lower than required for an ASST, they are higher than those for large airplanes presently operating; therefore, design, test and operational experience at the temperature will be useful to ASST.

Since titanium will be used in critical areas of the B-1 structure, this vehicle will provide a source of continuing advancement in the titanium production, design information, manufacturing methods refinements and joining techniques.

The first application of a 4000 psi hydraulic system was incorporated in the North American XB-70 aircraft. Satisfactory operation of this type system was demonstrated. The use of a 4000 psi titanium tubing hydraulic system was planned for the terminated prototype SST and is actually being used on the B-1. Experience to date on the XB-70 and the B-1 and other valuable experience will be gained for the future ASST.

b. PROPULSION

From a propulsion standpoint a supersonic transport engine tends to be unique in that it has to accept widely varying inlet conditions and, therefore, must be carefully tailored to the aircraft system. Engine/inlet compatibility is a very important factor to insure engine stability and good performance over the complete flight envelope and provide margins for inlet and engine transients.

The cruise performance is extremely sensitive to exhaust nozzle installation designs. Careful integration of the airframe afterbody and nozzle are extremely important to achieve minimum drag and reduce thrust losses. The noise requirements may cause two approaches: one is to limit the exhaust velocity to the desired noise level. This approach will cause extremely large engines which will be sized for takeoff and cause some range loss because they are oversized for cruise conditions. The other approach is to put some noise suppressors in the exhaust system which will cause some degradation in the nozzle performance.

The external environment around the engine is extremely hot. The engine operates full design RPM and temperature condition which is the maximum stress. This maximum stress is experienced during the total design mission of the aircraft. This last requirement

results in extreme emphasis on accessory and hot section design and, in particular, the turbine cooling technology. In any case, the engine will need the highest temperature turbine technology practical for reliable and economic operation. Programs should be initiated that will give consideration to fuel cooling of the turbine cooling air system for modulating turbine cooling air for off-design conditions, and all the schemes using high power extraction turbines and with good efficiency.

The continuing DoD-sponsored IR&D propulsion program and the U. S. Air Force's Advance Turbine Engine Gas Generator Project are providing the development of components for engine cores required in supersonic flight propulsion.

4. GENERAL DISCUSSION

The satisfactory accomplishment of a future supersonic transport for commercial use will require a substantial amount of technology hardware, development in breadboard, prototype and experimental form. All major subsystems to be incorporated in an Advanced Supersonic Transport require advanced technology, now under investigation by the military and NASA. Among the more important are:

- Automatic flight control for precise management of climb
- Higher turbine inlet temperatures
- Airframe and engine cooling concepts
- Hydraulic, pneumatic and electronic systems to insure dependability in a high temperature environment
- Improved stability and control
- Load alleviation and mode control

One of the important features to an economically competitive ASST is advanced engine technology to be compatible with the environment. The important items are quiet engine technology for high thrust engines, wide operational flexibility, long life and reduced specific fuel consumption and lightweight engine technology.

One of the military programs which could provide a great benefit to a future ASST would be the advanced composites program. Significant weight advantages can be attained provided reliable polymer and metal matrix composites are established for the higher

temperature requirements of the ASST. The design, manufacturing and operational use of advanced composites must be continued in order to provide the confidence and know-how for the designers to build efficient long life structures. Experience is being gained on the application of boron composites through military programs. The F-14 actually incorporates boron composites in the horizontal stabilizer and the F-4 and F-111 are service testing major components.

The relevancy of military development expected for this proposed aircraft is as follows:

AIR VEHICLE	
Configuration	Low
Structure	Low
Flight Control	High
PROPULSION	
Basic Design	High
Total Engine	Low
AVIONICS	
Communications	Moderate
Navigation	Moderate

An estimated program schedule for an Advanced Supersonic Transport is shown in Figure 2.

In summary an Advanced Supersonic Transport development plan will require careful integrated considerations of safety, operational economy and competitiveness with other countries' similar aircraft. A technology base has been generated by the military and NASA to permit the design of a Mach 2.5 to 3.5 aircraft. Selection of the appropriate technology and integrating it for a viable commercial system requires an outstanding engineering and management undertaking. Most of the major advancements needed to permit a proposal of an aircraft meeting the ASST requirements are and can only be funded by government R&D. The military establishments currently have some of these necessary projects in progress. Therefore, the technology base

will continue to be transferred to commercial aircraft designs such as the ASST. The application of the technology through development, testing and simulation tasks and facilities will transfer at a moderate rate. However, the direct hardware transfer will be low. As in the past the major portion of hardware transfer will occur in the propulsion systems, primarily due to the fact that the initiation and development of large engines incorporating the latest technology are nearly out of reach for a private venture.

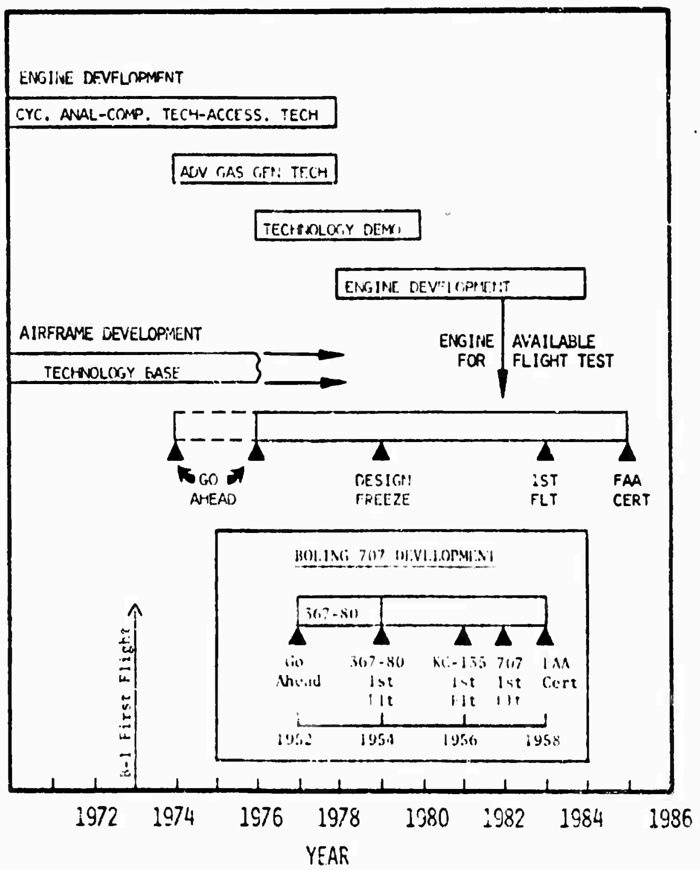

FIGURE 2

ASST - PROGRAM SCHEDULE

SECTION III

NATURE, TIMING AND TREND

A major difference in design philosophy between civil and military is that commercial aviation stresses safety, passenger comfort and economy, while the military stresses adequate mission performance. For this reason the feasibility of technology incorporated in an aircraft and much of the hardware and equipment is first demonstrated on military systems. When the technology has been validated and the reliability of the hardware and equipment proven, then the application to airlines is accomplished. At that point and time there usually is a data bank for the designer of commercial aircraft to use with a large degree of confidence. Some of the typical examples of this technology transfer are new materials applications such as titanium structures, augmented flight control, inertial navigation, high bypass ratio turbofan engines, hydraulic systems, and many others.

The amount of transfer to commercial aircraft design is greatest when military programs are in being at the same aircraft manufacturer. For example, in the late 1940s and early 1950s there existed a substantial amount of military aircraft development at the Boeing Company. From this, the Boeing Model 367-80 and the 707 were generated. However, from the middle 1950s through the early 1960s only the XB-70 was produced by the Boeing Company for the military. Lockheed started the development of the C-141 in 1960. However, this aircraft was designed and developed with known technology. The XB-70 was essentially a research aircraft and the new technology it demonstrated was of limited use for commercial aircraft. The only other large aircraft program started in the early 1960s was the concept formulation and contract definition phase of the CX-HLS which became the C-5A. As a whole in this time period, the technology transfer from military programs of large aircraft to civil commercial airplanes slacked considerably. This was caused partially by the increased emphasis on ballistic missile and space programs. Also, during this time, the aeronautics technology base being developed by NASA and the military laboratories for aeronautical systems was not being increased.

The design and know-how acquired in an aircraft company is reflected by the competence of the design team. These design teams have a wealth of data to call on, such as, the company's independent research and development program, results of research and technology published by government laboratories, military design handbooks, specifications and design criteria. However, the important design decisions for the configuration and airframe design details are their own. In the design of large aircraft for commercial use, a minimum amount of hardware transfer from military aircraft is reflected in the configuration. The technology base such as airfoil sections,

high lift data, stability and control, system design data, and structural design is supported by many government R&D programs and is applied directly. In the other major subsystems such as propulsion, avionics and integrated equipment, technology and hardware transfer does occur.

The era of "wide body" jets came into being by the foresight of major airframe manufacturers. To support these efforts, the most significant transfer from the government was the technology base in aerodynamics, structures, flight control and propulsion. Avionics components were obtained from vendors and designed to ARINC specifications. The only relevancy existing in the avionics field is the fact that most of the avionics contractors have R&D military programs employing the same technology.

Everyone is aware of the major and extensive development and production program for a larger airliner today which represents over a billion dollar venture. The total engineering manpower required for a large jet transport development is in the order of 3,000 people and at the peak of manufacturing there are as many as 8,000 additional personnel involved for a period of 25 to 30 months. The early 707 and DC-8 aircraft required approximately one quarter of this manpower and the super DC-8 and advanced 707s only one half of this total. In addition, many large facilities are required. Test facilities such as laboratories, wind tunnels, static test and fatigue test, simulators, together with large computers are essential. It is important to note that the Boeing 707 prototype, the KC-135 and the 707-120 required a total of 3900 hours wind tunnel test time to first flight, while the 747 required 15,600 hours of wind tunnel test to first flight. The structures test program for the 707 cost an estimated 8.0 million dollars while the 747 cost is estimated at 58.83 million dollars. The flight test hours required to FAA certification were 789 hours for the 707 and 1444 hours for the 747. For manufacturing subassembly and final assembly buildings are required in addition to the completely integrated vehicle function and checkout buildings. Boeing has an estimated 250 million dollars in facilities at one site and subcontractors used multi-million dollar facilities directly for a 747 aircraft. The prime aircraft company generates the design and its details, conducts necessary development tests and completely assembles the aircraft for flight test and commercial certification. Also, many equipment subcontractors and vendors are necessary. Major portions of the DC-10 and 747 are built and assembled at subcontractor's plants such as Convair, Northrop, Goodyear, de Havilland Aircraft of Canada, Ltd., and others. A major problem is to achieve a satisfactory mating of the major parts at the final assembly.

The recent re-establishment of prototype programs in DoD will assist significantly in providing demonstrations for new concepts,

new materials application and new design techniques. Some of these approaches are supercritical wing, composite structures, augmented wing for STOL, jet lift for STOL and V/STOL, elastic mode stabilization, 4000 psi hydraulic system, etc.

The timing for the application of technology and/or hardware to commercial aircraft varies and is dependent upon the items under consideration and their need to achieve the performance and/or safety and comfort requirements required by commercial aviation. The high bypass ratio turbofan was applied to civil aviation in two years. The application of these propulsion systems was the only way the designer could produce a satisfactory large aircraft without employing a very large number of engines. The application of titanium to commercial aircraft is gradual and still depends on need. On manufacturing technique and cost, for example, the DC-8 used titanium in 1.8% of its structure weight and the DC-10 has increased this to 6.6%. Fibrous composite structures will require about fifteen years for full application to commercial aircraft. The application of inertial navigation systems to a commercial airliner has required over ten years. This was partially due to the security classification of the details of the system and the cost, as well as the need, for its application in long range flights.

This discussion on the nature, timing and trend of technology and hardware transfer would not be complete without a relevancy assessment of the three important parts necessary for the creation of a commercial aircraft. These are the technology base, the development base and bits and pieces of hardware. Reference has been made to each of these in the foregoing discussions, however, a summarization is appropriate.

The technology base necessary for the design of new commercial aircraft has been and will continue to be provided by government R&D programs and independent research and development. This effort did not receive adequate support when emphasis was placed on missile and space programs. However, it is currently on the increase.

The development base represented by military ownership of ground and flight test facilities, flight test beds and manufacturing and assembly plants was large after World War II but has been reduced considerably in the 1960s with aircraft companies constructing their own.

The hardware transfer from military programs to civil aircraft has been reduced significantly with fewer similar military predecessor aircraft. An assessment of the relevancy of military contribution in the development base and hardware transfer to commercial airliner development is shown in Figure 3.

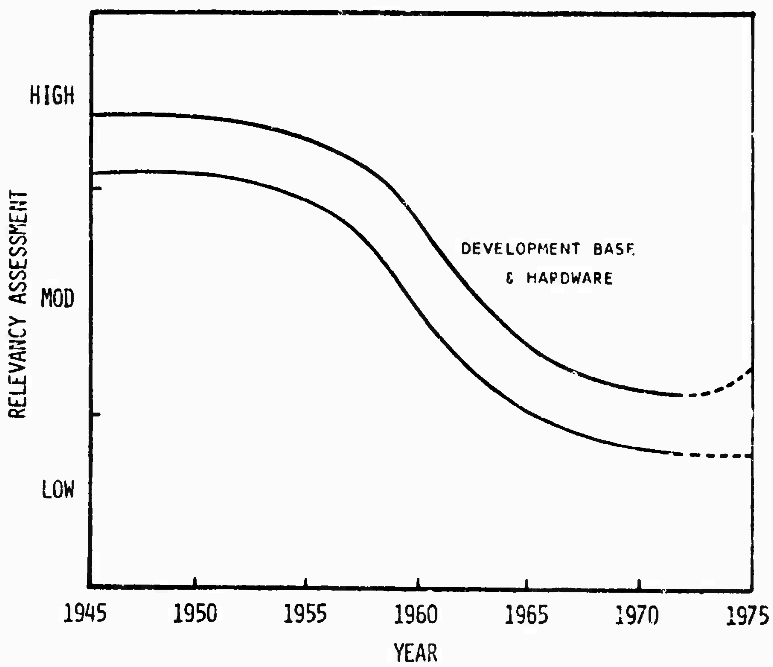

FIGURE 3

MILITARY DEVELOPMENT CONTRIBUTIONS TO COMMERCIAL AIRLINERS

SECTION IV

OBSERVATIONS AND FINDINGS

The military technology and hardware developed for the post-World War II swept wing jet powered aircraft provided the basis for and means by which the first commercial subsonic jet transports were developed and acquired. These aircraft represented by the Boeing 707 and Douglas DC-8 gained considerably from the F-86, A-3D and B-47 swept wing technology, the Pratt & Whitney J-57 engine and military avionics components.

A reduction in large military aircraft development programs beginning in the mid-1950s diminished the transfer of hardware to civil aircraft. The aircraft industry maintained its aeronautics know-how from other military advanced development efforts, independent research and development and government laboratory R&D programs.

From the general design point of view, the development of the large "wide body" jet transports required no major new technology other than the large high bypass turbofan engine. A closer scrutiny of the design details of modern jet transports will reveal that the airframe, flight control, landing gear and total vehicle avionics have incorporated many advanced features. These design features such as improved airfoil sections, titanium structures, augmented flight control, inertial navigation, etc., are derived directly from government and military R&D.

The recent initiation of DoD prototypes together with major advancements in R&D will demonstrate the feasibility and operational performance of new concepts. These activities will then provide necessary data for the design of commercial aircraft such as STOL, transonic and supersonic transports.

The trend in transfer of technology and hardware from the military to large subsonic commercial aircraft is downward.

The trend for technology transfer for the future in STOL transports is upward because of major new military programs in this area. The future for the ASST is uncertain though much is being accomplished to establish the technology base for a reliable, economical and competitive aircraft. All efforts would have to be accelerated if such an operational vehicle is desired by 1985.

APPENDIX 9

AERONAUTICAL R&D FUNDING

JOINT DoD-NASA-DoT
"R&D CONTRIBUTIONS TO AVIATION PROGRESS"
(RADCAP) STUDY

KELSEY P. SCHLOSSER
USAF/AFSC (ASD/XR)
PANEL CHAIRMAN

AUGUST 1972

APPENDIX 9

AERONAUTICAL R&D FUNDING

Index

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SECTION I

INTRODUCTION

Each of the other appendices of the RADCAP Study contains estimates of costs associated with the development of the specific hardware or technology. This appendix shows, in toto, the historical funding levels and cost trends associated with aeronautical research and development. An examination of these levels and trends should help to provide an understanding of the emphasis that has been and is being placed on aeronautical R&D by the various segments of the avaiation community.

One point needs special emphasis. The funding data from 1945 through 1971 shown on the figures in this appendix reflect obligations or expenditures actually experienced (or estimated as actual experience) during those years, while the 1972 and 1973 data are budgetary (planned) obligations or expenditures. Therefore, the 1972 and 1973 data showing increases from 1971 represent expected funding based on assessments of anticipated requirements. This study, if performed in 1974 or later, might reveal that 1972 and 1973 actual obligations or expenditures were lower than reflected in this appendix.

The primary source for the fiscal year funding data used in the RADCAP Study was the Joint DOT-NASA Civil Aviation R&D (CARD) Policy Study, February 1971, as updated by Booz, Allen Applied Research, Inc., in January and February 1972 for inclusion in this report. Other funding and cost data contained in this report were obtained from the files of various Federal agencies participating in this study, a general literature search, and discussions with several Government and industry representatives. These sources are listed in the Bibliography to this appendix.

SECTION II

DEFINITIONS AND EXPLANATIONS

Federal defense funds include those for the Army, Navy, Air Force, Advanced Research Projects Agency (ARPA), the Aircraft Nuclear Propulsion (ANP) Program of the Atomic Energy Commission (AEC), and the R&D funds reimbursed by the Government to industry as allowable overhead charges on procurement contracts. The R&D dollars reflected herein include basic and applied research, and development funds. The primary source was the funding obligations in the "Project List" of the Five Year Defense Plan (FYDP). It should be noted that not all of the projects classified as Aeronautics in the "Aircraft and Related Equipment" sections of the FYDP were included in the base data. Such things as bomb sights, fire control systems or antisubmarine warfare equipment are weapons carried by aircraft and were excluded from the definition of Aeronautics. Also, funds for such projects as pilotless aircraft (e.g., Snark, Quail, Regulus and Dyna Soar) were classified as Aeronautics, even though these projects were categorized as "Missiles" or "Space" within the FYDP. The R&D figures also include estimates for the construction of R&D facilities, military and civilian salaries, and other support costs. In addition, prototype aircraft development is included which, also, includes the construction of full-scale test hardware and complete aircraft, and their test programs. The R&D funds reimbursed by the Government to industry as allowable overhead charges on procurement contracts were computed as 80% (based on the ratio of Government aerospace sales to total aerospace sales) of the total IR&D funds available to industry less that IR&D allocated to civilian sales, from which those IR&D funds on contracted R&D are deducted; these latter funds are included in the funds data obtained from the FYDP.

Federal non-defense funds include those for the National Aeronautics and Space Administration (NASA) and Federal Aviation Administration (FAA). The data reflected in this appendix were obtained from budget documents available for these organizations dating back through 1945.

Industry funds include non-reimbursed industry independent research and development (IR&D) and specific development (SD) funds (approximately half of the total aeronautical R&D funds available to industry), and those funds provided by universities and foundations. (The other half of the aeronautical R&D funds available to industry are included in the federal defense category above as funds reimbursed by the Government to industry as allowable overhead charges

on procurement contracts. Also excluded from industry IR&D funds are those IR&D funds on contracted R&D, which are included in the Federal categories above.) IR&D funds include independent research not reimbursed to industry including that IR&D allocated to civilian sales, other technical effort (OTE) and bid and proposal (B&P) activities. Specific development usually involves "cutting metal" to a much larger degree than does IR&D. When a concept has reached the point that its economic advantages justify a risk, a company may invest in development of a prototype, etc., in preparation for production. These funds, expended by a company on which it expects a return, are defined as SD funds. SD funds include only civil type aircraft. Development funds for military aircraft are included under the federal defense definition above. Both IR&D and SD funds were computed as percentages of net sales (total IR&D at 5 1/2% and SD at 1 1/2%) and were derived from discussions with a military commercial aerospace vehicle manufacturer, a military and commercial engine manufacturer, a helicopter manufacturer, a major general aviation aircraft manufacturer, and a review of Congressional records for data pertaining to IR&D associated with avionics, as well as reviews of cost data available on various aircraft.

Funding data were collected from many sources and many estimates and interpolations were made to complete the extensive data sample. The search for detailed aeronautical R&D funding data ranged from almost non-existent information in the fifties, except for bits of information in Congressional records, to detailed Congressional records in the middle and late forties, to detailed budget data from the Federal agencies in the sixties. Changes in defense budgeting policies and procedures over this time period also complicated the collection of data and development of estimates. The accuracy of the annual funding data presented in this appendix is, therefore, questionable, but the magnitude of the annual expenditures and the resulting trends are, probably, about as representative of actual conditions as can be expected to be portrayed.

SECTION III

OVERVIEW

Figure 1 shows that the trend of the availability of R&D funds

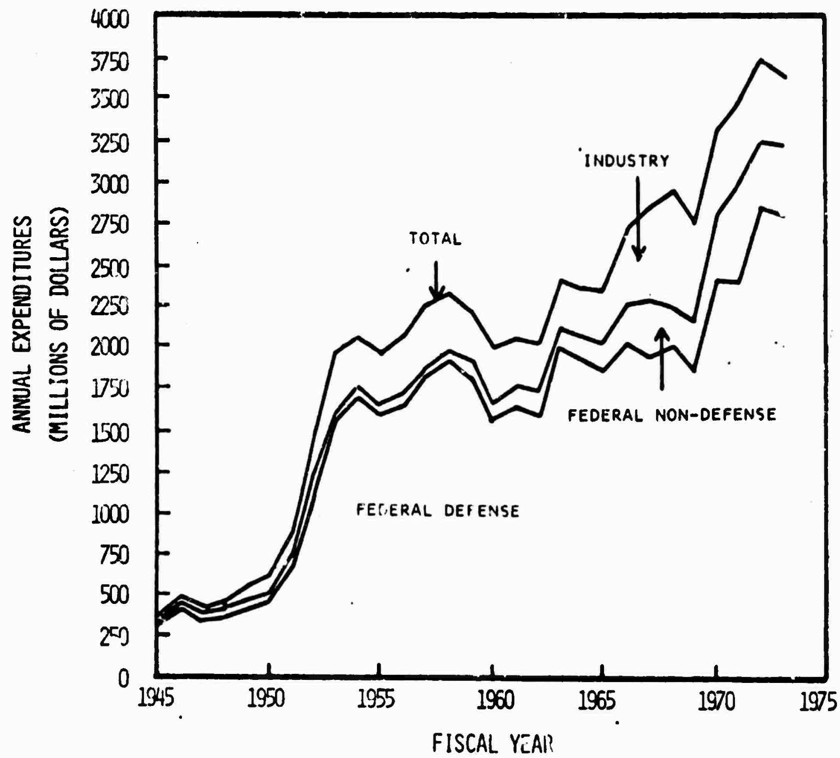

Figure 1. Sources of Aeronautical R&D Funds, Annual Expenditures (Then Year Dollars)

Source: Table 1.

for aeronautics has grown impressively over the years since 1945 (the data limit for this study), with the sharpest increase occurring from 1950 to 1954. Since 1954, the availability of funds has also shown an increase, but at a slower rate than the 1950-1954 period. The increasing rate has again accelerated beginning in 1970. Without a complete reversal of national aeronautical goals, it is anticipated that the growth in total aeronautical R&D funds will continue, although periodic annual decreases can be expected.

TABLE 1

SOURCES OF AERONAUTICAL R&D FUNDS
ANNUAL EXPENDITURES
(MILLIONS OF THEN YEAR DOLLARS)

FISCAL YEAR	FEDERAL DEFENSE	FEDERAL NON-DEFENSE	INDUSTRY	TOTAL
1945	$ 311	$ 31	$ 23	$ 365
1946	418	38	28	484
1947	349	31	37	417
1948	362	44	48	454
1949	414	55	70	539
1950	441	60	91	592
1951	684	66	164	914
1952	1102	116	277	1495
1953	1535	79	339	1953
1954	1686	56	343	2085
1955	1600	48	320	1968
1956	1658	52	353	2063
1957	1802	51	392	2245
1958	1909	60	356	2325
1959	1813	76	339	2228
1960	1578	80	329	1987
1961	1660	84	306	2050
1962	1614	108	304	2026
1963	1991	144	284	2419
1964	1939	140	304	2383
1965	1864	153	353	2370
1966	2013	253	445	2711
1967	1931	359	565	2855
1968	2004	255	673	2932
1969	1851	298	609	2758
1970	2399	402	514	3315
1971	2434	543	477	3454
1972	2831	415	490	3736
1973	2793	436	402	3631

Source: Bibliography reference number 1 (Table C-13, page C(47)).

DoD (Federal defense) aeronautical R&D funding has increased over the years, with rather sharp rises from 1950 to 1954 and from 1969 to 1973, and a significant rise from 1960 to 1969. During the past decade and into the early seventies (from 1960 to 1973), Federal defense funding increased by approximately 77 percent, from

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$1.578 billion to $2.793 billion. The latter figure is also 77 percent of the total FY-1973 anticipated expenditures for aeronautical R&D. Thus, in interpreting funding trends for aeronautical R&D as a measure of the quality and quantity of the contributions made to aeronautical technology, it can be forecast that DoD contributions to aeronautical R&D will continue to be substantial in the future.

During the same time period (from 1960 to 1973), Federal non-defense funding for aeronautical R&D increased by approximately 445 percent, from $80 million in 1960 to $436 million in 1973. Within this funding category, NASA's aeronautical R&D funding increased by approximately 822 percent, from $32 million to $295 million. Thus, these trends and increases also should assure that substantial contributions to aeronautical R&D will continue to be made by Federal non-defense agencies in the future.

Industry funds expended for aeronautical R&D have increased only 22 percent since 1960, from $329 million in 1960 to $402 million in 1973, less than the Federal non-defense total, after reaching a high of $673 million in 1968. The most disturbing point to be derived from Figure 1 is that, from 1968 to 1973, a period of only five years, these industry non-reimbursed funds for aeronautical R&D have decreased by 40 percent. In addition, the IR&D funds reimbursed by the Government to industry as allowable overhead charges on procurement contracts, included as part of the Federal defense funds discussed above, decreased from $481 million in 1968 to $273 million in 1973, a 43 percent decrease in five years. Based on industry funding levels and current industry funding trends, it appears that industry will contribute less in the future than it has in the past to aeronautical technological advances.

Aeronautical R&D funding trends also indicate that Federal defense contributions to the advancement of aeronautical technology, measured as a percentage of the total R&D funds available, have been on the decline over the total time period of the study. This trend is visible in Figure 1 but is emphasized when converted to percentages of total funds available as shown in Figure 2. Over the long trend, while federal defense's proportionate share of the total funds has been decreasing, industry and Federal non-defense have been picking up some of the slack, especially during the 1963 to 1968 time period. These trends have reversed since 1969.

It is interesting to note that, while industry's proportionate share of the aeronautical R&D funds was decreasing from 1958 through 1963, the total number of companies in the aircraft, missile and aircraft engine industry decreased from 1,339 in 1958 to 1,085 in 1963, with those employing 5,000 or more people decreasing from 29

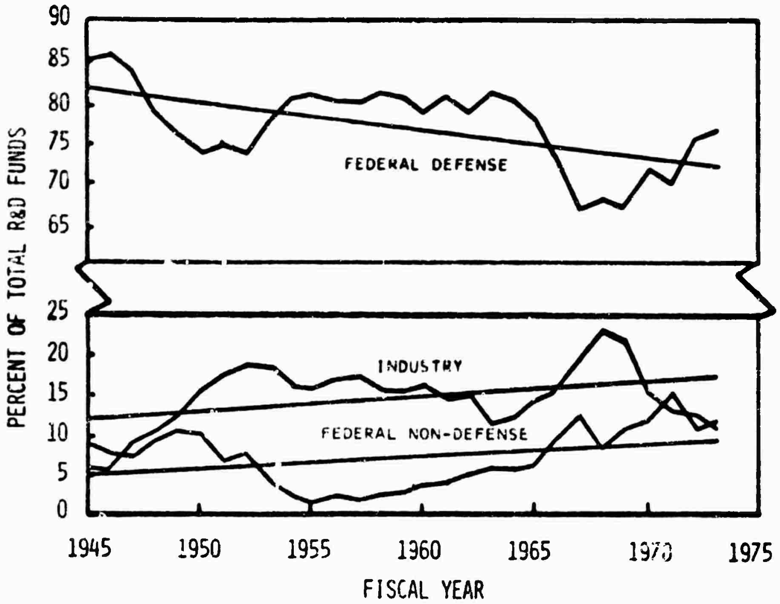

Figure 2. Sources of Aeronautical R&D Funds, Percent of Total Annual Expenditures

Source: Table 1.

to 24. Although an accurate count of the current number of companies is not available, the internal functional expansion of companies and the number of mergers since 1963 indicate that the number has continued to decline. From 1963 to 1968, however, the total aeronautical R&D funds available to industry increased each year; this is true even when these funds are converted to 1973 dollars. This indicates that from 1964 through 1968 less and less companies were sharing in more and more funds. Since 1968, however, it appears that less and less companies are sharing in less and less funds.

Economic escalation has had a noticeable effect on the purchasing power of aeronautical R&D funds, as reflected by comparing Figure 3 with Figure 1. Measuring from 1954 (the high point after the rapid build up which began in the late forties) to the estimated expenditures for 1973, the trend is still increasing for all funding sources even with economic escalation considered. The downward trend from 1954 to 1962 has been reversed during the past ten years to where the increasing trends are very noticeable, especially since 1969. These trends indicate that the total aeronautical R&D community and each of its elements have been provided with both increasing funds and increasing purchasing power over the years. Since 1968, however, industry has shown a noticeable decrease.

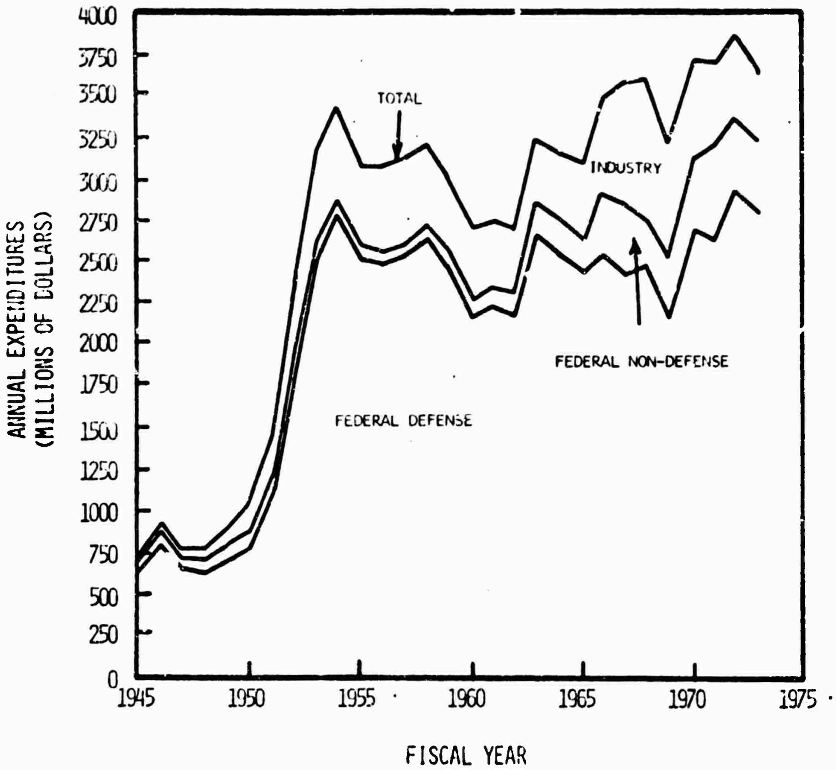

Figure 3. Sources of Aeronautical R&D Funds, Annual Expenditures (1973 Dollars)

Source: Table 2.

This appendix is a funding analysis, a look at the dollars being used by the aeronautical R&D community. A more specific analysis of technological advances by the aeronautical R&D community, covered by other appendices in this study, would show how a significant portion of the Federal defense funding was indirectly transferred to civil aviation through the experience and expertise that it provided the aerospace industry. Two excellent examples are that the Boeing 707 airliner and virtually all of its successors and competitors are based on the aerodynamic layout of the B-47 bomber (developed in the late 1940's) and their turbofan engines evolved from the Pratt and Whitney J-57 of 1950. Military requirements and funding are responsible for the technical leadership that has supplied approximately 75 percent of the aircraft currently operated by the free world's airlines. The increasing trend of available aeronautical funds, even when economic escalation is considered, is encouraging, but the current decreasing trend for industry is discouraging.

TABLE 2

SOURCES OF AERONAUTICAL R&D FUNDS
ANNUAL EXPENDITURES
(MILLIONS OF 1973 DOLLARS)

FISCAL YEAR	FEDERAL DEFENSE	FEDERAL NON-DEFENSE	INDUSTRY	TOTAL
1945	$ 620	$ 61	$ 46	$ 727
1946	798	72	54	924
1947	643	57	68	768
1948	628	77	83	788
1949	702	93	119	914
1950	767	104	159	1030
1951	1089	105	261	1455
1952	1758	185	441	2384
1953	2472	127	546	3145
1954	2773	92	564	3429
1955	2508	75	502	3085
1956	2475	77	527	3079
1957	2517	71	547	3135
1958	2633	83	491	3207
1959	2450	103	458	3011
1960	2144	109	447	2700
1961	2216	112	409	2737
1962	2164	144	408	2716
1963	2655	192	378	3225
1964	2572	185	403	3160
1965	2427	199	463	3089
1966	2571	323	568	3462
1967	2408	447	705	3560
1968	2441	311	819	3571
1969	2165	348	713	3226
1970	2680	450	574	3704
1971	2617	584	513	3714
1972	2931	429	507	3867
1973	2793	436	402	3631

Source: Table 1 and bibliography reference number 10.

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SECTION IV

DISCUSSION

REASONS FOR INCREASES AND DECREASES IN R&D FUNDS:

Figure 1 is reshown here as Figure 4, except that parenthetical

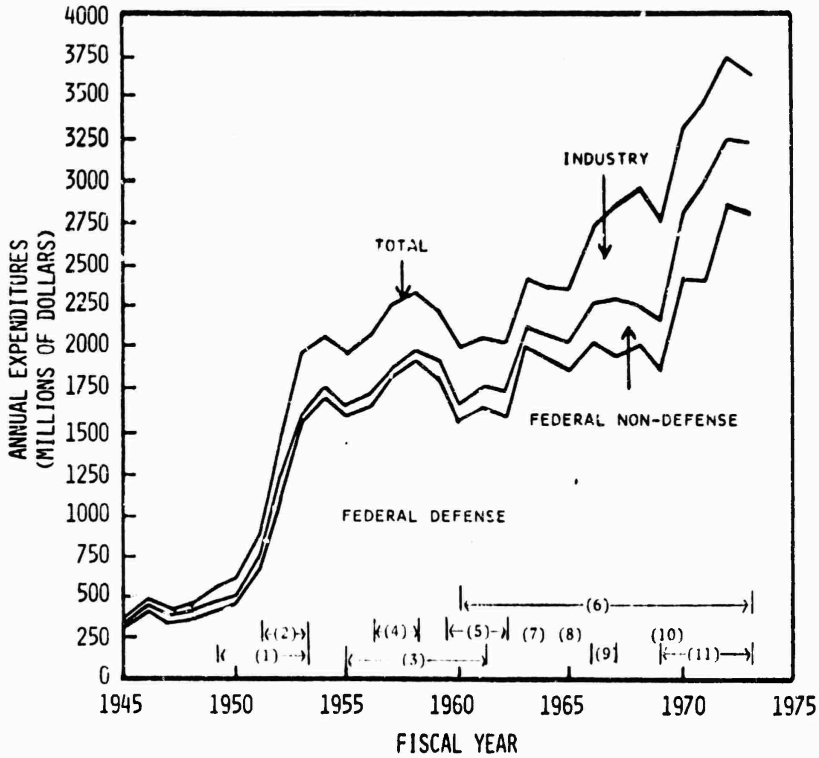

Figure 4. Sources of Aeronautical R&D Funds, Annual Expenditures (Coded to Reflect Funding Increases and Decreases)

Source: Table 1 and bibliography reference number 1.

numbers have been added to reflect the primary reasons for funding increases and decreases depicted by the graph. Explanations for these increases and decreases follow and correspond to the numbers at the bottom of Figure 4:

(1) The increase from 1949 to 1953 mirrors the transition from the subsonic propeller aircraft of the Army Air Corps to the subsonic jet aircraft for the Air Force. Also, during this time period, subsonic jet aircraft gave way to supersonic jet aircraft.

(2) The increase from 1951 to 1953 shows continuation of the jet aircraft development and construction of NASA's Unitary Wind Tunnel.

(3) AEC's ANP program was active during the 1955 to 1961 period.

(4) The increase from 1956 to 1958 reflects the emphasis on the supersonic fighter and subsonic bomber development programs. Also, the Army's HU-1A and K-17 programs were active during this period.

(5) The rather deep trough reflected during the 1959 to 1962 time period is due to completion of the supersonic fighter and subsonic bomber development programs of the 1950's and prior to the beginning of the development programs for the advanced fighters, bombers and transports (F-111, AMSA, C-5), and completion of the Army's HU-1A and K-17 programs and prior to the beginning of the development programs for the CH-47 and LOH.

(6) From 1960 to 1973, NASA's aeronautical R&D funding increased by approximately 822 percent, from $32 million to $295 million.

(7) In 1963, funds peaked for advancement of the major disciplines (propulsion, avionics, structures and aerodynamics).

(8) The dip in 1965 probably is due to the cutback, cancellation or completion of the tri-service V/STOL, CV-7A and LOH programs.

(9) From 1966 to 1967, the FAA emphasized applied engineering for designing, building and testing a prototype SST.

(10) The dip in 1969 is due, in part, to the $216 million reduction in the C-5A program and increases in the Navy's VSX and F-14 programs.

(11) The increases from 1969 through 1973 for federal defense aeronautical R&D funds are due primarily to increases in the Air Force's F-15 and B-1 programs, increases and subsequent decreases in the Navy's F-14 and S-3A programs, increases in the Army's HLH, UTTAS and AH-56 programs, and decreases in the funds reimbursed to industry as allowable overhead expenses on procurement contracts. The increases from 1969 through 1973 for Federal non-defense aeronautical R&D funds are due primarily to increases in NASA's V/STOL efforts and the aerodynamics associated therewith and their quiet engine program, increases in FAA's microwave landing system, instrument landing system, and stage three air traffic control system and decreases due to termination of the SST effort.

Although Federal non-defense funds are projected to increase in fiscal year 1973, Federal defense and industry funds are projected to decrease. Some of the major reasons are discussed above. National emphasis on issues other than aeronautical R&D is probably, also, involved in the decreasing availability of such funds. President Nixon stated in his January 1972 State of the Union message to Congress that 1973 is the first time in twenty years the United States has brought defense spending below the level of domestic human resource spending. The economic problems currently being experienced by the industrial complex associated with aeronautics are not expected to be reversed in the immediate future, except that more of their talent is likely to be directed toward the solution of the environmental issues.

GOVERNMENT AERONAUTICAL R&D FUNDING BY TYPE OF R&D:

Figure 5 shows the Government aeronautical R&D funds divided

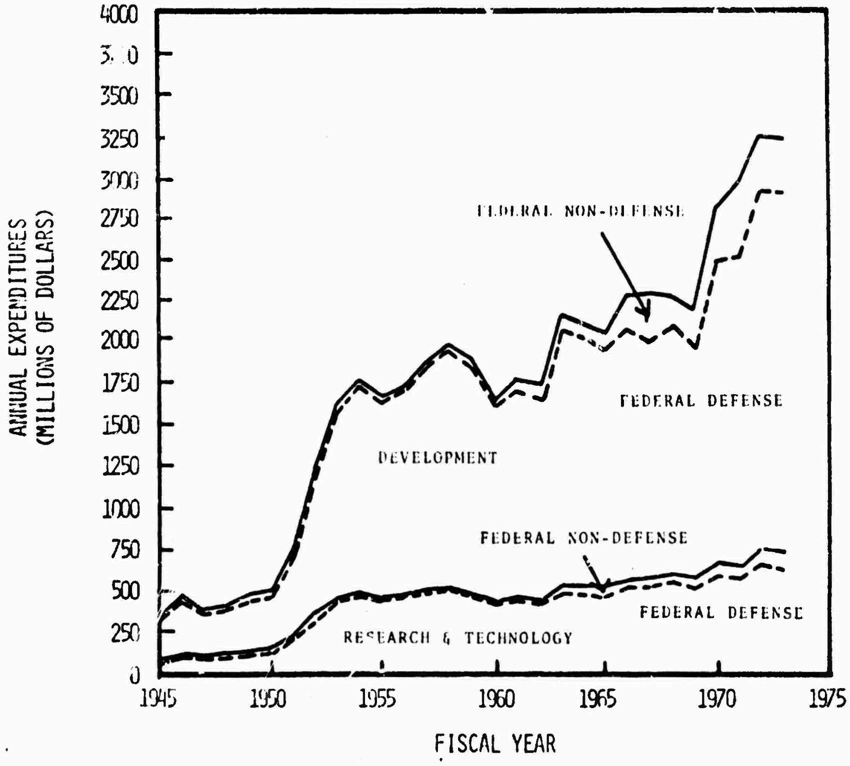

Figure 5. Government Aeronautical R&D Funding (Then Year Dollars)

Source: Table 3.

TABLE 3

GOVERNMENT AERONAUTICAL R&D FUNDING BY TYPE OF R&D
ANNUAL EXPENDITURES
(MILLIONS OF THEN YEAR DOLLARS)

FISCAL	RESEARCH & TECHNOLOGY			DEVELOPMENT			
YEAR	FED DEF	FED NON-DEF	TOTAL	FED DEF	FED NON-DEF	TOTAL	TOTAL
1945	$ 65	$ 11	$ 76	$ 246	$ 20	$ 266	$ 342
1946	86	13	99	332	25	357	456
1947	75	11	86	274	20	294	380
1948	82	15	97	280	29	309	406
1949	98	19	117	316	36	352	469
1950	113	19	132	328	41	369	501
1951	194	23	217	490	43	533	750
1952	316	40	356	786	76	862	1218
1953	425	27	452	1110	52	1162	1614
1954	453	19	472	1233	37	1270	1742
1955	431	17	448	1169	31	1200	1648
1956	449	19	468	1209	33	1242	1710
1957	488	19	507	1314	32	1346	1853
1958	499	17	516	1410	43	1453	1969
1959	465	17	482	1347	59	1406	1888
1960	411	11	422	1167	69	1236	1658
1961	429	14	443	1231	70	1301	1744
1962	415	24	439	1199	84	1283	1722
1963	485	44	529	1506	100	1606	2135
1964	475	48	523	1464	92	1556	2079
1965	462	57	519	1402	96	1498	2017
1966	510	42	552	1503	211	1714	2266
1967	526	50	576	1405	309	1714	2290
1968	551	58	609	1452	197	1649	2258
1969	516	63	579	1335	235	1570	2149
1970	588	76	664	1811	326	2137	2801
1971	578	80	658	1856	463	2319	2977
1972	654	87	741	2177	328	2505	3246
1973	630	109	739	2163	327	2490	3229

Source: Bibliography reference number 1 (Table C-15, page C(50)).

into research and technology and development funds. After the sharp increase in the early fifties, these funds remained rather stable until 1969, when another upward trend began. The largest portion of the R&D funds reflected on this chart is, of course, for the development of prototype and test aircraft. Figure 5 highlights the

large proportionate share that the Federal defense agencies contribute to both the R&T and development areas. It follows, then, that more technology advancements logically can be expected from the military sponsored programs. As shown earlier, this has occurred.

It is believed that funds expended for research and technology is one measure of future benefits to be derived in aeronautics. Research leads to advancements in any discipline, and aeronautical research accomplishments lead to hardware development 10 to 15 years after research is completed. The availability of research and technology funds shows an increasing trend over the years. As Figure 5 shows, and as emphasized by Figure 6, Federal defense's and

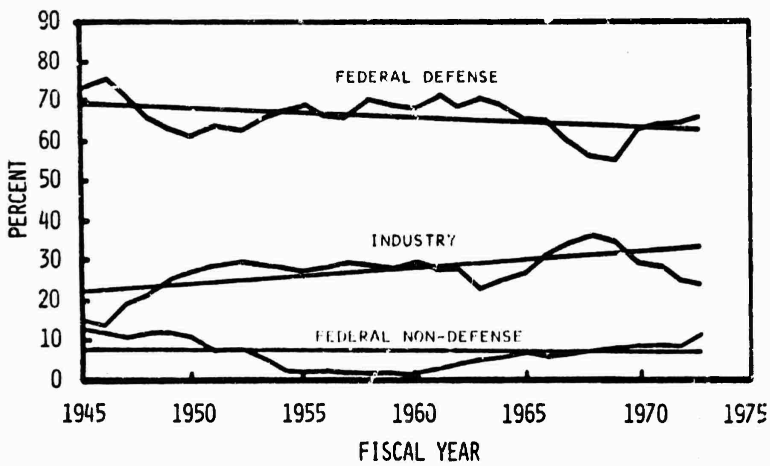

Figure 6. Sources of Aeronautical Research & Technology Funds, Percent of Total Annual Expenditures

Source: Table 3 and bibliography reference number 1.

Federal non-defense's proportionate shares of aeronautical research and technology funds have decreased over the years, while industry's proportionate share increased. Since 1968, however, these trends have reversed. Federal defense's proportionate share of the total aeronautical research and technology funds increased from 56.2 percent in 1968 to 65.6 percent in 1973 and Federal non-defense increased from 5.9 percent in 1968 to 11.4 percent in 1973; industry's proportionate share of the total aeronautical research and technology funds decreased from 37.9 percent in 1968 to 23.0 percent in 1973. Based on these later trends in research and technology funding, it appears that the Federal agencies will provide proportionately more of the significant contributions to advancements in aeronautics in the future.

Economic escalation has had somewhat of a leveling effect on Government aeronautical R&D as shown in Figure 7, although slightly

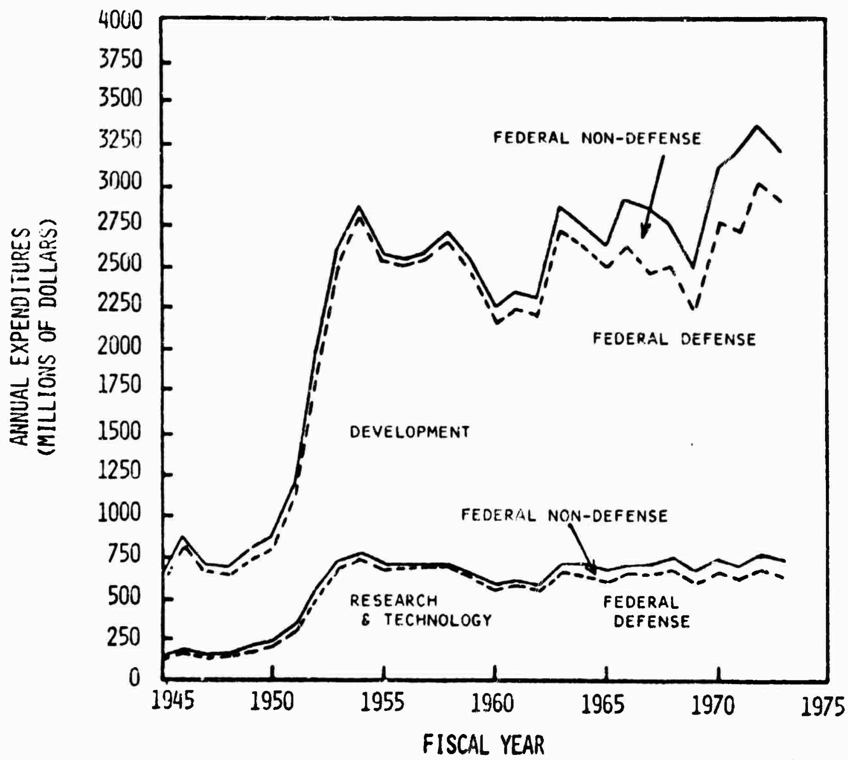

Figure 7. Government Aeronautical R&D Funding (1973 Dollars)

Source: Table 4.

upward trends are visible since 1954. Increasing trends are more pronounced during the last five years in "development" funds for both Federal defense and Federal non-defense, and in "research and technology" funds for Federal non-defense. Federal defense aeronautical "research and technology" funds, however, have experienced a slightly decreasing trend during the five year period from 1968 to 1973 due to economic escalation, dropping from $671 million in 1968 to $630 million in 1973. Thus, the purchasing power of dollars available for "research and technology," believed by many to be the basis for the future of aeronautics, has remained almost unchanged, while that available for "development" has slightly increased.

Research actually provides the technical tools that in due course will be incorporated into specific products. Thus, availability of a body of research knowledge for utilization is important

TABLE 4

GOVERNMENT AERONAUTICAL R&D FUNDING BY TYPE OF R&D
ANNUAL EXPENDITURES
(MILLIONS OF 1973 DOLLARS)

FISCAL	RESEARCH & TECHNOLOGY			DEVELOPMENT			
YEAR	FED DEF	FED NON-DEF	TOTAL	FED DEF	FED NON-DEF	TOTAL	TOTAL
1945	$129	$ 22	$151	$ 490	$ 40	$ 530	$ 681
1946	164	25	189	634	47	681	870
1947	138	20	158	505	37	542	700
1948	142	26	168	487	50	537	705
1949	166	32	198	536	61	597	795
1950	197	33	230	570	71	641	871
1951	309	37	346	780	68	848	1194
1952	504	64	568	1253	122	1375	1943
1953	684	44	728	1787	84	1871	2599
1954	745	31	776	2028	61	2089	2865
1955	676	26	702	1832	49	1881	2583
1956	670	29	699	1804	49	1853	2552
1957	682	26	708	1835	45	1880	2588
1958	688	24	712	1945	59	2004	2716
1959	628	23	651	1821	81	1902	2553
1960	558	15	573	1586	94	1680	2253
1961	573	18	591	164[illegible]	93	1737	2328
1962	556	32	588	1603	112	1720	2308
1963	647	58	705	2008	134	2142	2847
1964	630	64	694	1941	122	2063	2757
1965	602	74	676	1825	125	1950	2626
1966	651	54	705	1920	269	2189	2894
1967	656	62	718	1752	385	2137	2855
1968	671	71	742	1768	242	2010	2752
1969	604	73	677	1562	274	1836	2513
1970	657	85	742	2023	365	2388	3130
1971	622	86	708	1995	498	2493	3201
1972	677	90	767	2254	339	2593	3360
1973	630	109	739	2163	327	2490	3229

Source: Table 3 and bibliography reference number 10.

to the continuity of the development process. If civil aviation (or Federal defense) research were reduced, the effects might not be felt for 10-15 years, but development engineers would eventually find themselves unable to effect substantial improvements in applied

technology, because the basic scientific knowledge had not been generated. Continued and consistent Federal funding of aeronautical research is important to assure the maintenance of a strong civil aviation technical base. It would appear that those Federal agencies with statutory responsibility to advance civil aviation must be prepared to take a more active role in funding civil aviation research.

AERONAUTICAL R&D FUNDING AS A PERCENTAGE OF THE GROSS NATIONAL PRODUCT (GNP)

The Gross National Product (GNP) also has increased each year since 1945, except for the two decreases experienced in 1946 and 1949. A very significant observation, however, is that the availability of aeronautical R&D funds, taken as a percentage of the ever-increasing GNP, has suffered a severe reversal in the former upward trend. Since 1954, aeronautical R&D funds have been a sharply declining portion of the total GNP, as shown in Figure 8.

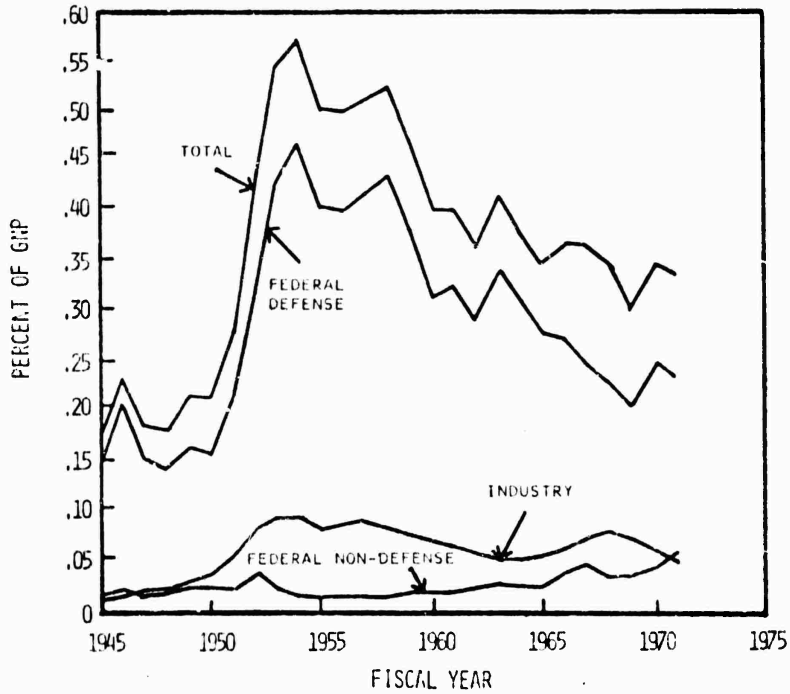

Figure 8. Sources of Aeronautical R&D Funds, As a Percent of the Gross National Product

Source: Tables 1 and 5.

TABLE 5

GROSS NATIONAL PRODUCT(1)
(MILLIONS OF THEN YEAR DOLLARS)

1945	$211,945	1960	$503,734
1946	208,509	1961	520,097
1947	231,323	1962	560,325
1948	257,562	1963	590,503
1949	256,484	1964	632,400
1950	284,769	1965	684,900
1951	328,404	1966	749,900
1952	345,498	1967	793,500
1953	364,593	1968	865,700
1954	364,841	1969	929,095
1955	397,960	1970	974,126
1956	419,238	1971	1,040,500(2)
1957	441,134		
1958	447,334		
1959	483,663		

(1) Prior to 1960, excludes Alaska and Hawaii.
(2) Estimated by source "b" based on second quarter annual rate.

Sources:

a. Through 1968: Bibliography reference number 1 (Table G-5, page G(26)).

b. 1969 through 1971: Bibliography reference number 6.

President Nixon told Congress, in his January 1972 State of the Union message, that military expenses for fiscal year 1973 will amount to only 6.4 percent of the GNP, down from 9.5 percent in 1968. This percentage decrease will very likely carry over into military R&D, and probably into aeronautical R&D, and thus continue the present downward trend of aeronautical R&D as a percentage of the GNP.

AIRCRAFT DEVELOPMENT AND UNIT COSTS

The cost of developing aircraft has risen dramatically with the advent of increasingly more productive,* complex modern aircraft.

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* More productive in terms of operating cost per seat mile, ton mile, or other increased effectiveness measured by mission accomplishment

As shown in Figure 9, the trend for commercial and military trans-

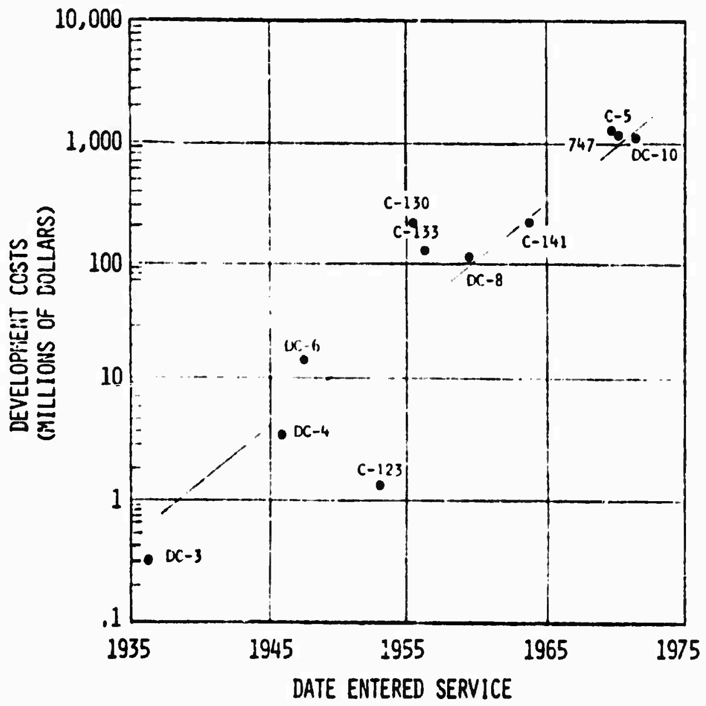

Figure 9. Transport Aircraft Development Cost

Source: Table 6.

ports is steeply upward. Also, Figure 10 shows a rapidly increasing trend in the cost of developing military fighter aircraft. In relatively recent times, it appears that aircraft development costs are about the same -- whether it is a transport or a fighter. Around 1955 to 1960 it cost about $100-300 million to develop a transport or a fighter, and in the early seventies it cost about $1-2 billion. It could be expected that the trends in development costs would differ between the two types of aircraft, and they do, but only slightly. Computing a trend line for only those transports developed since 1955, however, results in a trend very similar to the fighter aircraft development cost trend, being slightly lower but almost

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criteria, reference: Miller and Sawers, The Technical Development of Modern Aviation, and Handbook of Airline Statistics by the Civil Aeronautics Board, as well as operations research analyses and cost effectiveness comparisons of military aircraft.

TABLE 6

TRANSPORT AIRCRAFT DEVELOPMENT COSTS
(MILLIONS OF THEN YEAR DOLLARS)

AIRCRAFT	DEVELOPMENT COST (1)	DATE ENTERED SERVICE (2)	EMPTY WEIGHT (LBS) (3)
DC-3	$ .3	May 1936	18,300
DC-4	3.3	June 1946	46,000
DC-6	14.0	April 1947	57,200
C-123	1.3	Jan 1953	31,050
C-130	205.0	Sep 1955	59,328
C-133	122.0	April 1956	115,719
DC-8	112.0	Sep 1959	126,200
C-141	205.0	196[illegible]	134,203
C-5	1,206.0	Dec 1969	323,000
747	1,200.0	Jan 1970	348,816
DC-10	1,100.0	Aug 1971	230,323

Sources:

(1) Bibliography reference numbers 2, 11, 12 and 13.
(2) Bibliography reference numbers 3, 5, 8, 12 and 13.
(3) Bibliography reference numbers 3, 5 and 8.

parallel to the fighter trend line. In addition to development costs for transports and fighters being approximately equal, it appears that their rates of increase are approximately the same. Thus, large, complex airframes are nearly synonymous with dense, high performance, complex airframes insofar as development costs are concerned.

R&D funds are only a small part of the story relating to the cost to industry for bringing a new aircraft into the inventory. In new aircraft developments, the manhours associated with R&D are only about 2 1/2% of the total manhours that are necessary, including preproduction and production. Then there are materials acquisition, design and acquisition of rate tooling, subcontracting for long leadtime items, and many other expenditures the manufacturer must face just to get the vehicle ready for production. Federal programs generally fund the manufacturer as he proceeds, but civil programs require the manufacturers to finance the development effort from their company funds.

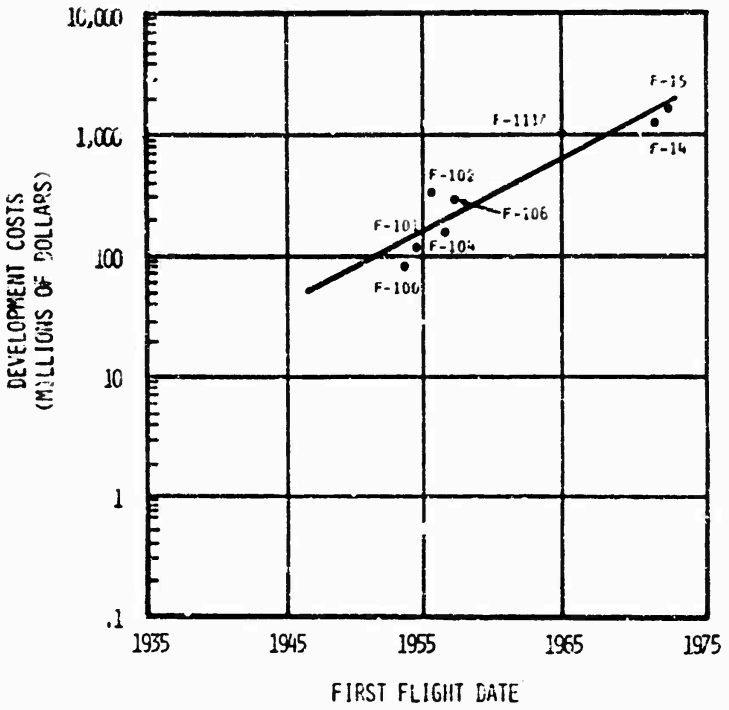

Figure 10. Fighter Aircraft Development Cost

Source: Table 7.

TABLE 7

FIGHTER AIRCRAFT DEVELOPMENT COSTS
(MILLIONS OF THEN YEAR DOLLARS)

AIRCRAFT	DEVELOPMENT COST(1)	FIRST FLIGHT DATE(2)
F-100	$ 84.3	May 1953
F-101	124.3	Sep 1954
F-102	322.5	Jun 1955
F-104	169.0	Mar 1956
F-106	293.0	Dec 1956
F-111A	1,129.0	Dec 1964
F-14	1,393.0	1971
F-15	1,753.0	1972

Sources:

(1) Bibliography reference number 13.
(2) Bibliography reference numbers 5 and 13.

Figure 11 shows, also in a dramatic way, how the unit prices

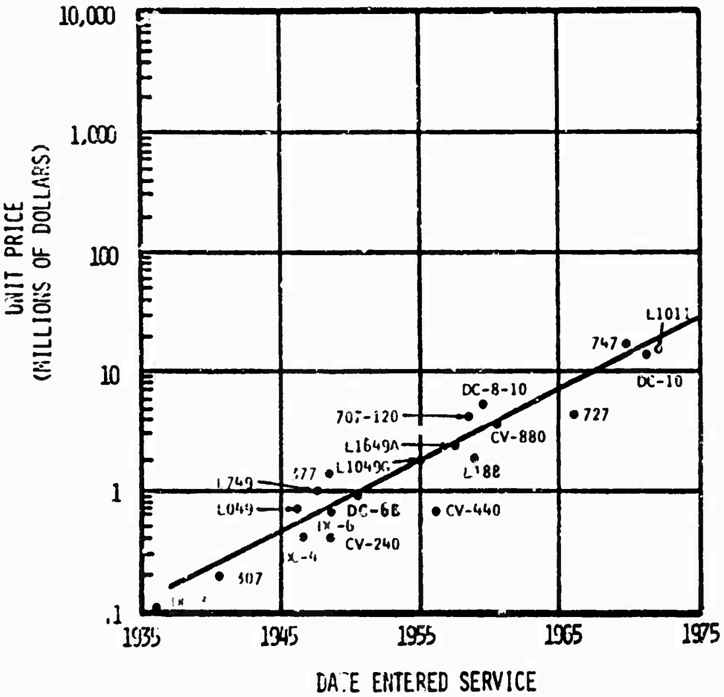

Figure 11. Civil Airliner Aircraft Unit Production Prices

Source: Table 8.

TABLE 8

CIVIL AIRLINER AIRCRAFT UNIT PRODUCTION PRICES
(MILLIONS OF THEN YEAR DOLLARS)

AIRCRAFT	UNIT PRODUCTION PRICE(1)	DATE ENTERED SERVICE(1)	EMPTY WEIGHT (LBS)(2)
DC-3	$ .11	May 1936	18,300
307	.19	Mid 1940	37,000
L049	.69	Feb 1946	62,000
DC-4	.39	Jun 1946	46,000
DC-6	.64	Apr 1947	57,200
L749	1.00	Autumn 1947	69,000
CV-240	.40	Jun 1948	29,500
377	1.47	Sep 1948	92,000
DC-6B	.94	Apr 1951	64,000

TABLE 8 continued.

AIRCRAFT	UNIT PRODUCTION PRICE(1)	DATE ENTERED SERVICE(1)	EMPTY WEIGHT (LBS)(2)
L1049G	$ 1.96	Jan 1955	82,500
CV-440	.65	Feb 1956	33,500
L1649A	2.53	May 1957	94,500
707-120	4.20	Oct 1958	118,200
L188	2.05	Jan 1959	61,000
DC-8-10	5.56	Sep 1959	126,200
727	4.50	Early 1964	82,000
747	18.40	Jan 1970	348,816
DC-10	15.50	Aug 1971	230,323
L1011	17.00	Mar 1972 (Est)	308,500

Sources:

(1) Bibliography reference numbers 3 and 12.
(2) Bibliography reference numbers 3 and 5.

of civil airliners have increased over the years. Unit production price increases are due partially to the increasing development costs and, also, to the preproduction costs just discussed, which the aircraft industries prorate to the unit sales that are made.

There are many reasons, which will be mentioned later, why development costs and unit prices of transport aircraft are increasing. One of the reasons is that the aircraft are getting heavier and, therefore, require more resources in the form of manpower, material and tooling to develop and produce. The costs of these additional resources are exceeding the growth in aircraft weight! Doubling the weight of an airplane more than doubles the cost to develop or produce it, as shown in Figures 12 and 13. If the costs of these resources exactly doubled as the weight doubled, the trend line in these figures would be flat, rather than increasing.

There are several cases where the cost per pound of aircraft developed or produced decreases as the weight of the aircraft increases, as reflected in Figures 12 and 13 (e.g., in Figure 12, development costs for the C-133 and DC-8, or the DC-10, C-5 and 747, and in Figure 13, unit prices for the CV-440 and DC-6B, or the DC-10, L1011 and 747). There are many reasons for such occurrences: different manufacturing methods, management efficiency, differences in accounting methods, less development costs to be amortized over the production units, type of material used in airframes and engines, number of engines per aircraft, types of avionics installation, aircraft performance, and others. However, these are individual

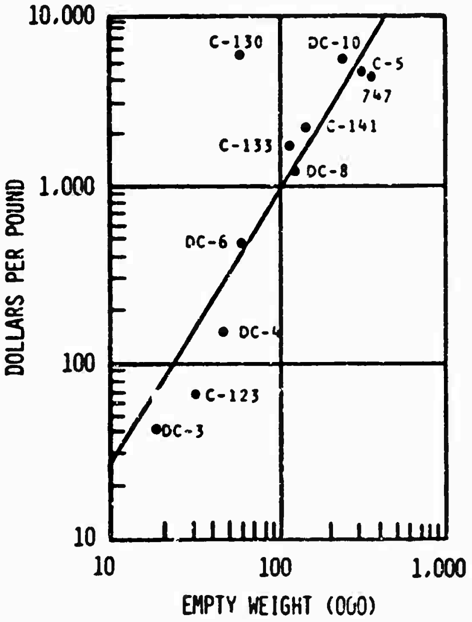

Figure 12. Transport Aircraft Development Cost Per Pound of Empty Weight (1973 Dollars)

Source: Table 6 and bibliography reference number 10.

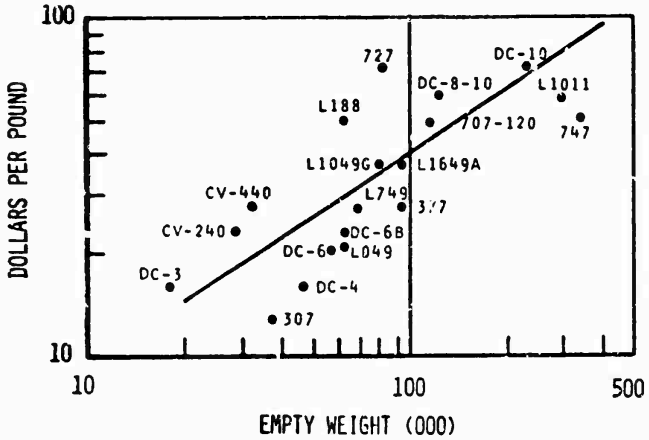

Figure 13. Civil Airliners Unit Production Price Per Pound of Empty Weight (1973 Dollars)

Source: Table 8 and bibliography reference number 10.

examples of peculiar and short-term trends, and projections of costs for future aircraft could easily go awry when based on such limited data points. For, the overall long-term trends show that as the aircraft empty weight increases, the cost per pound of empty weight increases rather sharply for the development phase and also increases for the production phase. It should be noted that these costs have been adjusted for economic escalation and are expressed in 1973 dollars.

The reasons for the increasing costs reflected in the five preceding charts, Figures 9 through 13, are many and varied. Some of the major reasons, other than economic escalation, are academically listed as follows: higher performance and mission requirements have made aircraft immensely more complex; preparing for production before the aircraft flew resulted in having to modify partially finished and finished aircraft and finished tooling; engineers' desire to change resulted in unnecessary divergences from the basic concept; changing production methods have altered design techniques and made them more complex; enormous and expensive design teams have been assigned to the increasingly complex aircraft development and preproduction efforts; higher standards of the -illities and safety are required by airworthiness and operational authorities from more complex aircraft, and more development is needed to obtain them; government procurement methods have changed, and these changes have complicated the acquisition process; government buyers were often more interested in the results than in costs; manufacturers had an almost open-ended line of credit with the government for military projects; the detail in and number of drawings and specifications have increased; the frequent government need for quick results.

On the other side of the coin, long military production runs are generally beneficial to civil aviation, from both technology improvement and cost reduction view points, in that they provide substantial production know-how, tooling, and continued search for new methods of manufacturing and management. Large quantity military production, with its accompanying production know-how, has the direct result of reducing unit prices. One of the best examples of price reduction in this manner is the military's early requirement for large quantities of aluminum aircraft, causing the price per pound of aluminum to decrease substantially. Another example is the military early requirement for large quantities of transistors and other electrical/electronic components, causing significant unit price reductions.

Aircraft system planners and designers are now continuously refining performance and other technical requirements to live within development and production funding constraints. Also, users of

aircraft, as well as test agencies, are being forced to reduce the numbers of aircraft to accomplish their designed tasks. This is especially true in the military, and, with little doubt, airline companies would also appreciate larger quantities of the new transports. It is obvious that the Government and the aerospace industry must continue to seriously attack the reasons for cost increases academically listed above.

COMPARATIVE TRENDS

Figure 14 provides a comparison of some of the most important

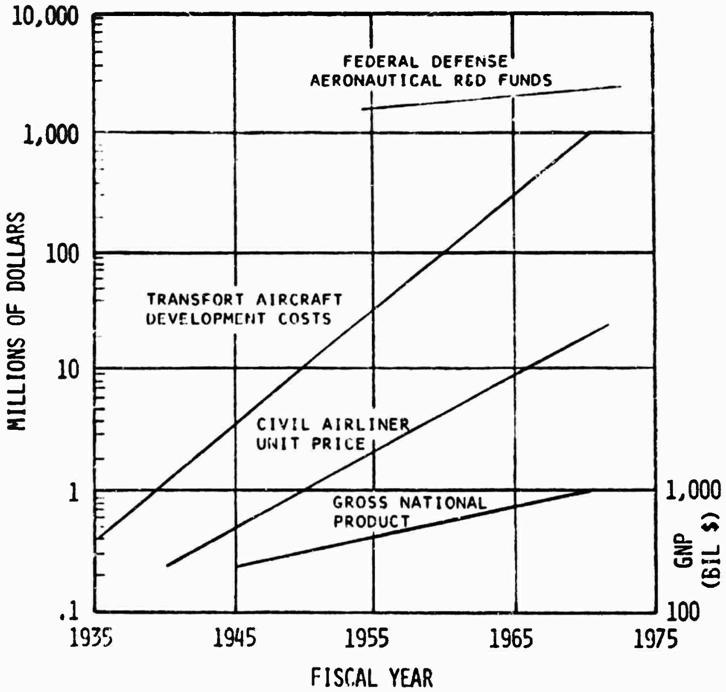

Figure 14. Summary Comparative Trends

Sources: Tables 1, 5, 6 and 8.

cost and funding trends that apply to aeronautical research and development. In comparison with the rise in the Gross National Product, the cost of new aircraft development and aircraft unit prices are climbing more rapidly, while the funds available for Federal defense aeronautical R&D are rising more slowly. This information would indicate that major new aircraft programs will either decrease in number or change significantly in nature, unless some of the trends are altered or reversed. Fewer program starts could result in a significant slowdown in the number of technological advancements made in aeronautics.

AIRCRAFT DEVELOPMENT STARTS

Related to the general funding picture in aircraft development are the procedures used in development and acquisition. During the 1940s and 1950s, prototyping was the standard procedure for developing and testing aircraft before production orders were placed. In the first jet bomber competition, for example, four companies responded to an invitation to bid on a jet powered bomber capable of a speed of 500 MPH, a service ceiling of 40,000 feet, a combat radius of 1,000 miles. Four companies responded, and all were accepted. These were the North American XB-45, Consolidated XB-46, Boeing XB-47, and Martin XB-48. Two of these -- the B-45 and B-47 -- were accepted for production.

Similarly, three prototypes were involved in a penetration fighter competition that was conducted in 1950. These were the McDonnell XF-88, the Lockheed XF-90, and North American YF-93. However, the outbreak of the Korean War diverted attention and funds to other types that were more suitable for quick production, and none of these prototype fighters were produced. The XF-88, though, became the basis for the F-101 ordered two years later.

Use of the prototyping approach began to decline in the 1950s, and in the 1960s very few programs were accomplished in this manner. With the implementation of the "fly-before-buy" concept in the last few years, however, advanced prototyping has been re-initiated as a method of doing business. The number of new military aircraft starts of all kinds, including experimental vehicles, has declined rapidly in the two decades -- from an average of about 15 a year in the early fifties, to about 6 a year in the early sixties, and to about 3 a year in the early seventies. What will occur in the future is uncertain, and undoubtedly will depend very much on the military threat that develops.

Figures 15 and 16 illustrate the significant downward trend in the number of new aircraft starts that has been occurring. Figure 15 shows the number of large aircraft, those in the 100,000 pound and over category, that have been developed by the military in the fifties and sixties, as well as those known that should first fly in the seventies. Figure 16 shows the same information on aircraft in the 25,000 to 100,000 pound category. Many observations on the impact of this trend could be made, but one message is clear -- the number of new military aircraft program starts has been sharply declining.

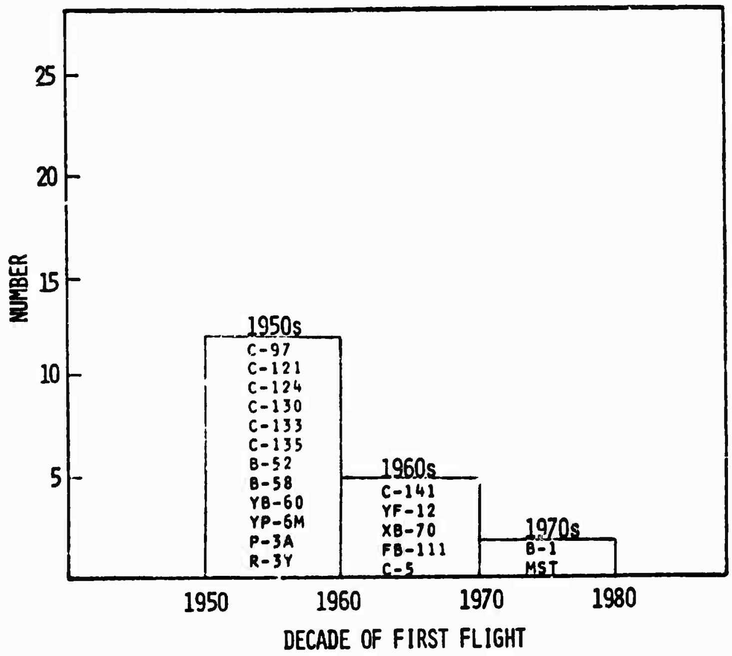

Figure 15. Military Fixed Wing Aircraft Programs (100,000 Pounds and Above)

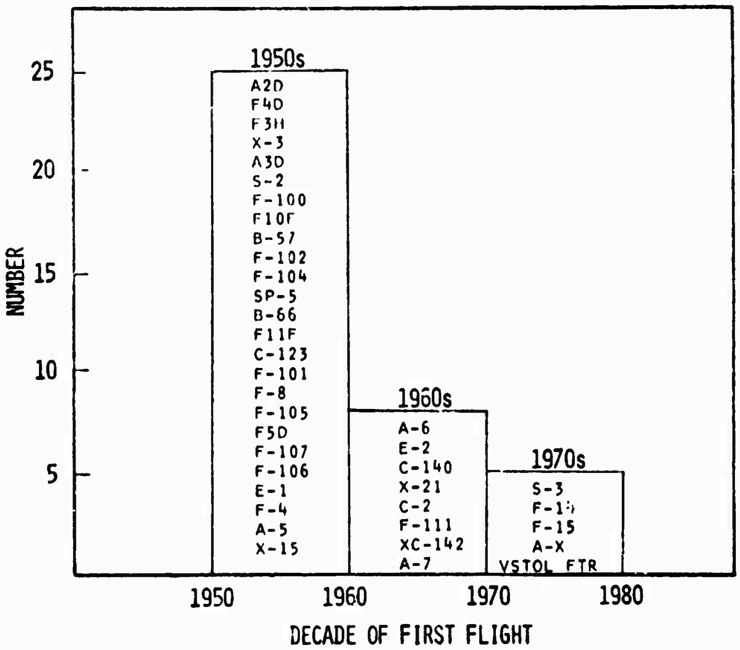

Figure 16. Military Fixed Wing Aircraft Programs (25,000 - 100,000 Pounds)

The importance of this fact lies in understanding that any successful industry grows on its momentum. Within the aircraft industry, that momentum is generated by the continuing development of new aircraft or prototypes, so that scientists, engineers, technicians and draftsmen maintain their proficiency, their expertise, their familiarity with the manifold problems of aeronautical development. It is difficult to design one new airplane every ten or fifteen years, which is now the fact in a majority of this country's aircraft companies, and maintain the necessary proficiency and, therefore, the momentum that in the past has carried the U. S. aviation industry to world-recognized technological superiority.

Consequently, it follows that in order to maintain the momentum that produces growth, there must be a continuing number of new aircraft program starts to challenge the inventiveness and ingenuity of the industry. Such programs can only be initiated by the requirements of the military services. It is the decision of the Congress to provide the funding that supports them.

If adequate funding is made available by the Congress, the U. S. aeronautical industry can continue to grow, and to maintain its strong position as a major earner of dollars in export markets.

If Congress does not support adequately the numbers of new aircraft program starts which will maintain the technological momentum of the industry, then the future prospects for that industry are gloomy.

SECTION V

AERONAUTICAL R&D FUNDING SUMMARY

The following summary observations on aeronautical R&D funding and the trends associated therewith are derived from the data of the preceding discussion.

The long term trend in the availability of funds for aeronautical R&D has been upward. This applies to all elements of the total -- Federal defense, Federal non-defense, and industry.

In terms of constant dollars (FY 1973), the trend is still upward over the years, though only slightly, for all elements of the total. However, during the past five years, the industry element is experiencing a downward trend.

In recent years, trends in the availability of industry funds for both research and development, and Federal defense funds for research, have been downward -- in contrast to the overall upward trends.

Development costs of new aircraft have been rising very rapidly -- at a rate much greater than trends in the availability of R&D dollars.

The rate of increase in development costs is much higher, and the rate of increase in the availability of aeronautical R&D dollars is much lower, than the rate of increase in the Gross National Product.

Trends in development costs and aeronautical R&D funding availability, as well as in new aircraft program starts, indicate that the number of new aircraft programs in the future will continue to decline, unless something very significant occurs in the cost and nature of aircraft development, or in an increased allocation of funds for these efforts.

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